CERTIFICATION OF APPROVAL

Improvement of Oil and Water Separation in Three-Phase Conventional Separator Using Hydrocyclone Inlet Device

by

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

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TRONOH, PERAK

December 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SYAFRI BIN MOHD YUNUS

ABSTRACT

This report entitled **Improvement of Oil and Water Separation in Three-Phase Conventional Separator Using Hydrocyclone Inlet Device**. The main objective is to investigate the effectiveness of HID in improving the oil and water separation process in a mature field with high percentage of water produced in the production. Mature field has always been related to production with high water produced, known as high water cut. A conventional separator cannot anticipate large inflow of water. Production with high water cut will reduce the separation efficiency and thus cannot recover hydrocarbon to its optimum. It has been found out that a Hydrocyclone Inlet Device (HID) can improve the hydrocarbon separation and maximize recovery of liquid hydrocarbon from fluid stream. HID is a device located at the inlet of separator and using cyclonic effect to enhance the separation process by inducing a centrifugal flow path within its tapered tubes. There are two stages of project milestone which are project development and implementation. Both stages are run within one year time frame. The scopes of study during project development are feasibility study and design prototype. As for project implementation stage, the scopes of work are construct prototype, design and conduct experiment, performing data analysis and evaluation of results. A small, basic prototype of gravitational separator with HID was constructed to study the cyclonic effect of oil and water separation. The investigation was done by conducting several experiments using separator with and without HID from low to high water-oil ratio percentages. The result shows that HID will always improve the efficiency of separation in term of separation time reduction about 20 to 35% regardless of water cut percentages. Volume of oil recovered increased through improved separation up to 14 %. Emulsion thickness is also reduced faster than conventional separator at 1st minute of separation. In conclusion, Hydrocyclone Inlet Device is feasible to retrofit with conventional separator as to improve the oil and water separation in high water production.

ACKNOWLEDGEMENT

Firstly I would like to praise Allah the Almighty, which have helped and guided me in completing my Final Year Project. I am grateful that the knowledge gained throughout this study is very relevant and useful to my current studying practices. A lot has transpired during this period of time and I am in debt to so many people who lent their support and expertise to me throughout this process.

My sincere and heartfelt thank to my Final Year Project supervisor, Mrs. Putri Nurizatulshira Binti Buang, who has always enthusiastically given me valuable input and guidance. I thank you for your patience and many hours of support providing advice, support and knowledge which will always be remembered and appreciated.

I would also like to express my full appreciation and gratitude towards Ir. Nazarudin Bin Ahmad and Ir. Ernesto C. Geronimo, Senior Engineer of Facilities Engineering Department at PCSB-PMO for helping me to acquire information and work out problems for my case study.

I would like to extend my appreciation to the staffs and technicians of Universiti Teknologi PETRONAS's Mechanical Engineering Department for all their guidance and assistance in helping me throughout the completion of the project.

I would also like to acknowledge my thanks to my course mates and friends who have always willingly to share ideas and sincere comments. The support and encouragement from the people above will always be pleasant memory throughout my life.

And lastly, and most importantly, I want to thank my family who have always prayed for my success and given their utmost moral support in my life. I hope I can always be there for them in the way they supported me.

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LIST OF ABBREVIATIONS

HID	-	Hydrocyclone Inlet Device
PCSB	-	PETRONAS Carigali Sdn. Bhd.
PMO	-	Peninsular Malaysia Operation
SBO	-	Sabah Operation
SKO	-	Sarawak Operation
EOR	-	Enhanced Oil Recovery
BS&W	-	Base, Sediment and Water

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

The hydrocarbon processing industry is struggling to meet global demand. Oil accounts for a large percentage of the world's energy consumption. The production, distribution, refining and retailing of petroleum taken as a whole represent the single largest industry in terms of dollar value on earth. The most common method of obtaining petroleum is extracting it from oil wells found in oil fields. Then, the extracted petroleum need to be processed prior to put up for sale.

A production separator is one of the main production facilities that are required during the hydrocarbon process. Basically, the main function of production separator is to separate the hydrocarbon liquids from the production wells into gas, oil and water phases for further processing or disposition.

PETRONAS is Malaysia's national petroleum corporation. This company is wholly owned by government and is entrusted to develop and adding values to the entire oil and gas resources in Malaysia. ***Carigali***, short form for PETRONAS Carigali Sdn. Bhd (PCSB), is one of PETRONAS wholly owned subsidiaries. It became fully involved in all aspects of exploration, development and production activities especially in crude oil and gas production in Malaysia.

PCSB's domestic operation is divided into three (3) regions which are Peninsular Malaysia Operations (PMO), Sarawak Operations (SKO) and Sabah Operations (SBO). In our offshore fields, there are green and brown fields. A green field is referring to a field at its optimum or constant production rate. In contrast, a brown or mature field is referring to a field at its declining production rate.

With improved technologies and higher demand for hydrocarbons, the Enhancement Oil Recovery (EOR) projects are applied in petroleum exploration and development. This is to optimize the hydrocarbon recovery. The recovery methods such as water injection and carbon dioxide flooding are used to extract oil that is brought to the surface by underground pressure. It is known as subsurface production enhancement activities. They can generally recover about 5 to 20% of the oil present, depending on types of recovery.

The production enhancement activities also can be done through surface facilities such as desander and descaling pipeline. In fact, these production enhancement activities also can be done in the separation process itself such as hydrocyclone separation technique.

Up until now, most of our platforms are still using the old design of separator which we know it as a conventional separator. This kind of separators are usually found in a big size and heavy weight and thus affects the space and loading requirements as well as cost of offshore structure. In recent years, a lot of researches have been done to solve these problems and develop more efficient techniques of separation. This research has led to the development of compact separator that promises a lighter and smaller size of separator than the conventional one.

The hydrocyclone separator is one of the compact separators. Of course there are other types of compact separator designs such as Diverter Plate, Half Pipe, and Vane Type. However, these types of compact separators are not as good as the hydrocyclone separator. The justification of why the author selecting the hydrocyclone as the best option is shown in the literature review section.

One of the components of a hydrocyclone separator is a cyclonic-inlet device which increases the speed of separation by coupling the affect of centrifugal force with gravity force. However, the application of new separation technology particularly in offshore platforms is not as widespread and rapid as the evolution of the technology itself. Currently, the trend is more towards business pull rather than technology push. Thus, new technology not really widely accepted.

1.2 PROBLEM STATEMENT

Matured fields have always been related to production with high water cut. A field is consider facing high water cut when there is at least 60% of water in its production well (Arnold, 1999). It is undesirable to deal with since the efficiency of oil and water separation in a separator is hard to control with high water production coming from its wells. The separation time for oil droplets to settle out from the water phase may not be adequate and lead to a relatively high amount of oil-in-water carried over to produce water treatment. Thus, reduce the oil production recovery.

For instance, Carigali took the operatorship of five producing oil fields, known as PM9, from EPMI. The takeover of PM9 also posed a greater challenge to PMO in managing bigger and more complex operations with ageing facilities and matured fields. These fields have reached decline period where facing high water cut in the production is a common production problem. (Ernesto, 2008)

With higher demand for hydrocarbons, a lot of researches have been done to develop more efficient techniques of separation to optimize oil recovery. Cyclonic separation is one of the improved technologies in separation technique; known as compact separator. It appears to be lighter and smaller size than current conventional separator. However, the entire conventional separator needs to be replaced with a complete set of compact separator which is clearly not feasible and economical.

In recent years, it was found that this cyclonic separation can be adapted in the conventional separator by retrofitting with a cyclonic-inlet device. It is known as Hydrocyclone Inlet Device (HID). It serves the same purpose as compact separator except it is only an inlet device which is mounted at the inlet of existing separator.

The application of HID has been proven at Angsi field; one of the green fields under PMO in Terengganu offshore. Angsi field has shown an improvement of hydrocarbon separation by increasing the oil recovery without major modification to the existing facilities. However, this application was not being applied in mature field with high water cut production. Hence, the interest of this project is to study the effect of hydrocyclone in high water cut production as to improve the separation.

1.3 SIGNIFICANCE OF STUDY

The importance of this study is basically to investigate how the inlet device can improve the efficiency of hydrocarbon separation process in terms of increasing the speed of separation and oil recovery in high water cut production. Thus, by having Hydrocyclone Inlet Device (HID) in the existing production separator will enable high water cut marginal well to be developed.

This study will also prove that it is not required to replace the entire conventional separator with a complete set of compact separator to improve the efficiency of hydrocarbon separation. But it only requires retrofitting the HID with existing conventional separator. This will give a great benefit to the Oil and Gas Operator Companies since they do not need to spend a lot of money to improve the efficiency of hydrocarbon separation. The installation of HID can be done without major modification to the existing facilities. Hence, it is clearly feasible and economical.

The recovery of crude oil can be maximizing with the usage of HID in the separator instead of relying on the Enhancement Oil Recovery (EOR) projects alone. As a result, the operator can recover as much oil as they can get from the particular field even it is from the mature field. In fact, it will extend the field's life cycle. By doing this, they can optimize the field's production level until the last drop of oil with the aim to meet the demand of hydrocarbon in our globalization.

1.4 OBJECTIVES AND SCOPES OF STUDY

The main aim of this study is to investigate how the usage of Hydrocyclone Inlet Device (HID) can be applied in the production facilities as one of the enhancement production activities through the separation process itself. It is anticipated that with a comprehensive understanding of the HID based on the literature review study and experiments conducted, it shall be clearer on how this cyclonic separation technique can be implemented in the production separator as to improve the efficiency of oil and water separation.

The key objectives to achieve this ultimate aim and the scopes of work are detailed as per below:

1. To review past and present uses of separation technology in oil and gas industry, particularly in application of compact separator in improving oil-water separation
   a) To summarize the separation history
   b) To gather data on the existing production separators in offshore PMO
   c) To briefly describe the conventional and compact separation technology for separation process
   d) To summarize the application of compact separator in the oilfield

2. To review basic theory, general applications of HID and its working principles.
   a) To justify why HID is selected as the best option of inlet devices to be applied in separator as to improve the hydrocarbon separation.
   b) To perform literature review on the application of HID in production facilities.
   c) To perform a case study on the installation of HID in V-1010 production separator at Angsi Field.

3. To investigate the effectiveness of HID in improving oil-water separation in high water-cut production in terms of separation speed and oil recovery.
   a) To design and construct a prototype of HID and 3-phase conventional separator.
   b) To design and conduct the experiments of oil and water separation using the prototype of separator with and without the HID.
   c) To investigate the capability of HID in improving the oil recovery by comparing the results in different percentages of water cut production.
   d) To investigate the capability of HID in controlling the emulsion problem in the oil and water separation.
   e) To correlate the relationship between percentages of water cut with retention time taken to see whether HID is able to increase speed of hydrocarbon separation even in high water cut production.
   f) To compare performance of separation efficiency based on reduced retention time using separator with and without the HID.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 SEPARATION HISTORY

The evolution of today's surface production facilities actually began for a long time ago. In the production stage of oil and gas industry, the processing or separation of hydrocarbon at oilfields has been practices since the mid of 1800s (JPT, 1999). The sequence of the evaluation of separation process is explained in the timeline as per below:

Table 1: Evolution of Separation Process Timeline

Year	Milestone
Early 1800s	• At the early stage of oil discovery, sump separation systems were used to collect the crude oil. • Sumps were dug to serve as surface reservoirs for production. • The associated gas was vented into the atmosphere • Sump separation systems had difficulties as surface water, dirt and other debris ran into these sumps.
1861	• Larger wooden tanks were made to replace the sump separation systems. • Gas and oil produced were separated in the flow tank, where oil being collected at receiving tanks while gas was vent into the atmosphere.
1863	• At this era, the technology of separation began to expand where the first separator was invented but was not considered practical until late 1800s. • During that time, gas was started to be recognized and being captured to serve as fuel for the drilling engines.

1867	• The wooden tank was then being replaced with bolted-iron tanks without any cover at the top. • Then, wooden roofs were placed at the top of the tanks to avoid rain and debris to enter.
1904	• As pressures increased, bolted iron tanks replaced barrels as separators. • The improvements of separation process come quickly where separators with level controller were invented and can handle pressure up to 150 psi
1904-1950s	• During this time, more advance controls, designs, and improved construction materials were highlighted in the evolution of separators. • Horizontal, dual-barrel separators were developed and are able to handle high gas flow or low liquid flow separation. • Horizontal, single-barrel separators were developed since they were more effective at high flow rates. • Up to three stages of separation became a common one to stabilize the hydrocarbon liquids produced from high pressure wells.

Source: JPT Frontiers of Technology-Surface Production Facilities (June 1999 Vol. 6)

Up until now, the separation process is still using the old design of separator which we know it as a conventional separator. This kind of separators are usually found in a big size and heavy weight and thus affects the space and load requirements and also cost of offshore structure. However, in recent years, a lot of researches have been done to solve these problems and develop more efficient techniques of separation. This research has led to the development of compact separators that are lighter and smaller than existing conventional separator.

2.2 SEPARATION PROCESS IN A CONVENTIONAL SEPARATOR

In oilfield processing of hydrocarbon, a mixture of fluids from reservoir were extracted to the well and flow to the wellhead before the fluids collected at wellhead manifold. Then the mixed stream will enter the separation module which is usually consists of first and second stage of separator.

In stage separation, the mixed stream goes through a separator where the first separation of liquid takes place. The liquid from the first separator is then sent into a second separator at a lower pressure. Here more gas is separated from the oil. This is done to obtain maximum liquid recovery. At this point, the mixed stream already separate to each phase and continue flow for further processing.

Basically, gas will flow to gas scrubber and gas compression module while oil will flow to storage tank for final oil treatment before export. Water will flow to water treatment system for disposal purpose. Figure 1 below shows the typical process flow of oil production facilities.

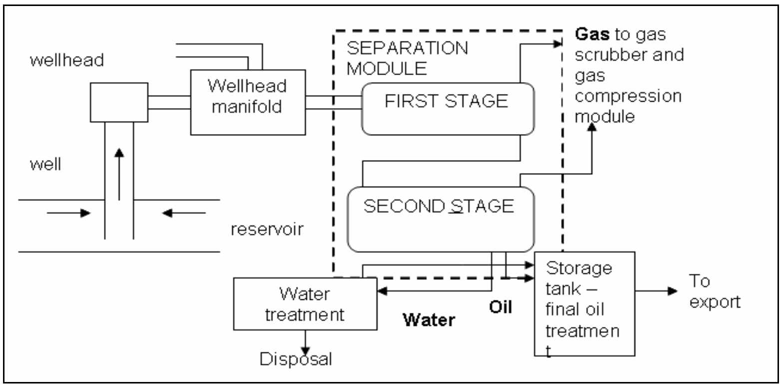


Figure 1: A Typical Process Flow of Oil Production Facilities

Source: Facilities Engineering Lecture Note: Separator (Mrs.Putri, January 2008)

2.2.1 Definition of Separator

Generally, separator is a pressure vessel designed to separate a mixture of fluids into its individual components that are not soluble in each other and have different in density for subsequent processing or disposition (M. Stewart, 2002).

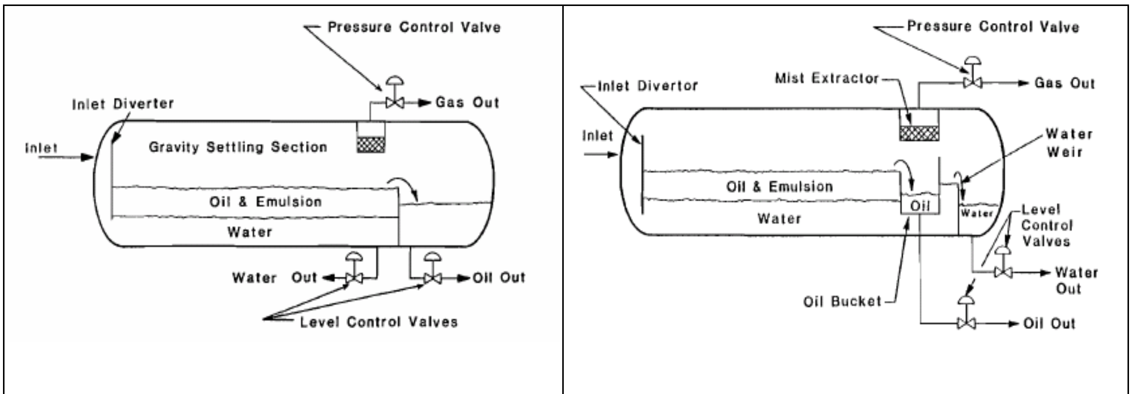
2.2.2 The Need for Separation

Separator is very important in production of oil and gas because certain downstream equipments cannot handle gas-liquid mixtures. For examples, pumps require gas-free liquid while compressors require liquid-free gas to function efficiently. The product specifications has limit on impurities such as oil should not contain more than one percent of BS&W (base, sediment, and water). Metering devices to measure capacity of oil or gas to be exported is inaccurate when other phase is present. Thus, a good separation is needed in surface production facilities (Arnold and Stewart, 1998).

2.2.3 Separator Classification and Designs

Separators are classified in two ways which are the position of the vessel and number of fluids to be separated (phases). The position of vessel can be horizontal or vertical. The number of phases tells the number of separate streams that leave a separator. For instance, a two-phase separator separates inlet stream into two fluids. Vertical and horizontal separators can both be two or three phase separators (Mary, 1998).

Normally, oil field platform is using three-phase separator while gas field platform is using two-phase separator. Three-phase separator is best to be applied for the oil and water separation in order to produce oil. In three-phase conventional separators, there are two main designs that are commonly used in oil and gas industry. There are Interface Level Controller and Bucket and Weir Design as shown in Figure 2 below.



a) Interface Level Control Design

b) Bucket and Weir Design

Figure 2: Designs of Three-Phase Separator

Source: Oil and Water Separation (Mary, 1998)

2.2.4 Basic Separator Construction

There are four main sections in a typical separator. The first section is an inlet diverter as primary section. This section removes most of liquid in the inlet stream. Slugs and large liquid particles are removed first. This minimizes gas turbulence and stops liquid particles getting mixed with the gas again. Second section is gravity settling as the secondary section. This section uses gravity to separate liquid from gas after the inlet stream speed has slowed down. The efficiency of this section depends on gas and liquid properties, particle size and the amount of gas turbulence (M. Stewart, 2002).

The third one is a mist extractor as the coalescing section where gas outlet is located. This section removes the very small droplets of liquid. This is the final stage of separation before the gas leaves the vessel. Finally is the liquid collection as the sump section where the liquids collect at the bottom of the vessel. Two things determine the capacity of this section is the rate of flow of well stream and liquid residence time (M. Stewart, 2002).

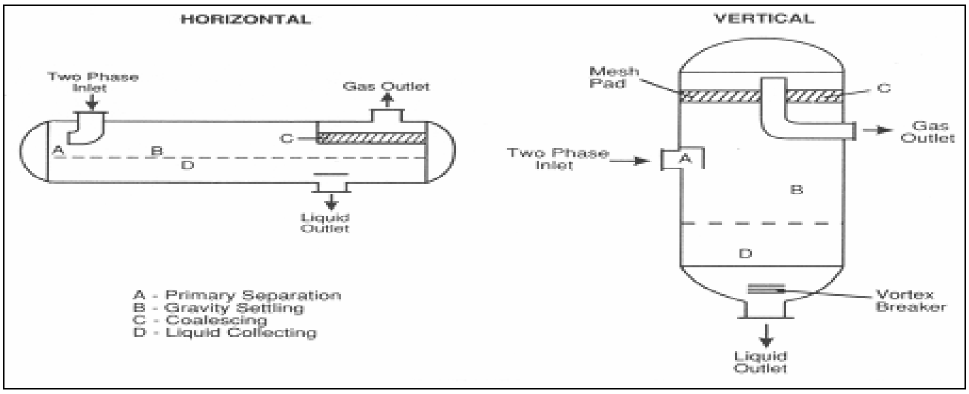


Figure 3: Four Main Sections in a Typical Separator

Source: Surface Production Facilities (M. Stewart, 2002)

2.2.5 Principles of Separation

Arnold and Stewart (1998) stated that there are 4 main principles of separation which are momentum, gravity, coalescing and equilibrium. As for momentum, it occurs at inlet diverter where it is the initial separation of gas phase from the free liquid phase known as gross separation. The mixed stream from the well hits the diverter and changes its flow direction. Fluids at different momentum are separated.

As for gravity, it occurs at gravity settling section. As the gas flows through this section, gravitational force causes small liquid droplets to fall out from gas stream. These droplets then fall to the gas-liquid interface at the droplet settling section. The range of droplet removed is about 100 to 400 micron.

For coalescing, it occurs at mist extractor. Before gas leaves the vessel, it flows through mist extractor, located at top of the separator. About 99 percent of the droplets above 10 micron will be removed. This is a refinement of the gross separation where it removes the remaining entrained mist which is very small liquid droplets from the gas phase.

The equilibrium process occurs at liquid collection. It provides retention time required to allow entrained gas to evolve out from the liquid phase and rise to the vapor space. After a certain period of time, the phases become equilibrium with each other. It separated naturally due to its density differences.

2.2.6 Retention Time

A certain amount of time is required to ensure that the water, oil and gas have separated within each other by mean of gravity and reached their equilibrium phase at prevailing temperature and pressure condition. If the residence time is not enough, gas has no time to rise from gas–oil interface. Retention time can be divided into two parts which are oil and water retention time.

For oil retention time, it is a time taken for the oil to coalesce into droplet sizes sufficient to fall. Similarly goes to water retention time, it is a certain amount of water storage is needed to assure that most of the large droplets of oil entrained in the water have enough time to coalesce and rise to the oil-water interface (Arnold and Stewart, 1998).

2.3 PRODUCTION ISSUES WITH CONVENTIONAL SEPARATOR

2.3.1 Limitation of Retention Time to Increase Additional Flow

The conventional separator therefore relies on an adequate retention time to ensure an efficient and clean separation of its oil and water phases. However, this retention time poses a limit to increase additional flow rate for fields undergoing production enhancement activities such as enhanced oil recovery projects (Nazarudin, 2005).

2.3.2 Limitation of Retention Time for High Water Production

Another problem faced by the daily operation personnel at production platform is controlling the efficiency of oil and water separation in a separator with high water production coming from its wells. This occurs in mature, brown fields. The high water cut (produced water ratio over fluid production) almost always comes with other production problems such as sand accumulation in separator and scale build-up in flow-lines.

There has been concern on the actual extent of the separation between oil and water phase for a high water production (above 60% water) system since the retention time for oil droplets to settle out from the water phase may not be adequate, leading to a relatively high amount of oil-in-water carried over to the produced water treatment system.

2.3.3 Effect of Production Problems – Emulsion

The present of emulsions can be troublesome in the operation of three-phase separators since the settling time required to achieve an acceptable separation may be longer than required to separate the gas. After certain duration of time, an accumulation of emulsified materials or impurities usually will form at the water and oil interface. This accumulation will also decrease the effective oil or water retention time in the separator, which will decrease the water-oil separation efficiency since it adversely, affects the liquid level control. Applying heat and addition of chemicals can helps to minimize this difficulty (Stewart, 2002).

2.4 COMPACT SEPARATION TECHNOLOGY FOR SEPARATION

2.4.1 Definition of Compact Separation

Nowadays, oil and gas companies are continuously searching for more effective ways to produce oil and gas. There are several types of modern separator that use the centrifugal force to separate fluids. They are known as compact separators. Basically, compact separators perform the same function as the conventional separators but somehow, they are using a smaller vessel. This is the result of using the centrifugal force instead of gravity force.

2.4.2 The Need for Compact Separation

The use of centrifugal force can affect the flow patterns to separate immiscible phases of different densities. In fact, this centrifugal action can somehow increased the affective force of gravity and this will make the separation occurs more rapidly. This is supported by the fact that the centrifugal force is thousand times greater than gravity force. Therefore it will increase the speed of separation by reducing the retention time (Arnold and Ferguson, 1999).

Besides, it only uses a smaller plan area for the same separation since the size of the vessel can be greatly reduced. This is very important in offshore platforms since the space is very limited at the platform. Moreover, by having a smaller vessel, it will help to decrease the loading requirement since the separator is now lighter than the conventional separator. This can help to greatly reduce the cost of offshore structure.

There are a few disadvantages of the compact separators. They are more sensitive to plugging with paraffin, sand, corrosion and erosion products as well as mechanical failure. Apart from that, the compact separators also have higher capital, operation and maintenance costs as compare to those conventional separators. They have some limitations but yet, still sufficient enough to go for many practical purposes (Arnold and Ferguson, 1999).

2.4.3 Selection of Inlet Device to be retrofitted in Conventional Separator

It was found that the separation with centrifugal force can be adapted in conventional separator by retrofitting with an inlet device. This inlet device serves the same purpose of a compact separator except it is only mounted at inlet section of existing conventional separator. There are several types of inlet devices that are available in the market such as Diverter Plate, Half Pipe, Vane Type and Hydrocyclone.

Each of them has its own working principle that differs within one another in terms of performance. Thus, selection of an inlet device can have a large impact on the efficiency of the separator since the performance of inlet device will affect the performance of other internals. Figure 4 below shows the overview of internals in three-phase separator.

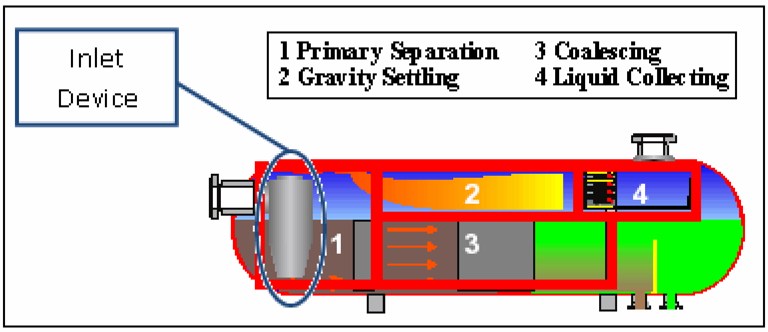


Figure 4: Overview of Internals in 3-Phase Separators.

Source: CDS Engineering (Victor and David, 2006)

Victor and David (2006) stated that an inlet device should have following functions:

i. *Ensure Good Gas and Liquid Distribution*

This is important for a good performance of separator because the distribution of the phases entering the gas and liquid gravity separation sections has to be as good as possible to optimize the efficiency of the separator. Poor distribution of phases entering can lead to a long residence times and reduce its efficiency.

ii. *Separate Bulk Liquids*

A good separation of liquids at inlet device will increase the separator efficiency by decreasing the separation load on the rest of the separator. In fact, it will make the separator operation less sensitive to changes in the feed stream. The examples of inlet devices with good liquid separation are vane type and hydrocyclone while half pipe inlets perform less well because they send both gas and liquid heading downward into vessel straightaway.

iii. *Emulsion Reduction*

Emulsion is always a problem in determine the efficiency of separation. Any inlet device that can eliminate or reduce emulsion can extensively improve separation efficiency of the separator. It even can cut operational cost by reducing chemicals usage. In this case, hydrocyclone is the best option to handle emulsion problem since the centrifugal forces applied can break down the emulsion formation.

From the basis of functions that an inlet device should have, it can be shown that hydrocyclone is the best options for selecting an inlet device as it fulfill all of the functions. This can be summarized in a Table 2 shown below:

Table 2: Comparison of Inlet Devices

Inlet Device Functions	Diverter Plate	Half Pipe	Vane Type	Hydro-cyclone*
i. Ensure good gas and liquid distribution	Average	Average	Good	Good
ii. Separate bulk liquids	Poor	Average	Good	Good
iii. De-foam	Poor	Poor	Average	Good

*Rating of Hydrocyclone is assumed that the design always include a perforated distribution baffle

Source: CDS Engineering (Victor and David, 2008)

2.4.4 Application of Compact Separator in Oilfield

A decade ago, there have been dramatic changes in the application of new technology to both gas–liquid and oil–water separations. A lot of researches and field testing driven by the need to reduce topsides weight and size for deepwater developments. These researches have led to development of compact separators that apply the used of centrifugal force to accomplish separation process in a vessel of much smaller diameter and length than a standard gravity separator (JPT, 1999).

However, compact separators were not always be a best option since the capital, operation and maintenance costs are much greater than conventional separators. It is a critical objective in all new field developments to reduce its life cycle cost. Correct use of compact versus conventional separators will make only a marginal difference in topside life cycle costs. Hence, the choice to use compact separators must be based on the full understanding of life cycle costs itself (Arnold and Ferguson, 1999).

2.5 HYDROCYCLONE INLET DEVICE

Hydrocyclone Inlet Device, (HID) is a device that is located at inlet of the separator. It is using the cyclonic effect to enhance the hydrocarbon separation process by inducing a centrifugal flow path within its tapered tubes. This will allows a bulk separation of the liquid phases and a coalescence of the dispersed droplets in the continuous phase of the underflow. A cluster of hydrocyclone used as an inlet diverter in a conventional separator extends the separator's capacity and reduce the emulsion thickness. Figure 5 below shows a diagram of hydrocyclone inlet device.

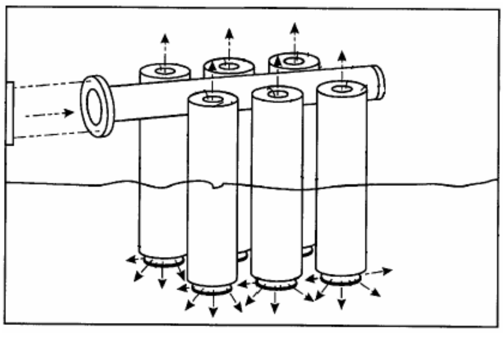


Figure 5: Hydrocyclone Inlet Device

Source: US Patent (M. West and Albert, 2003)

2.5.1 Working Principles of Hydrocyclone Inlet Device

In conventional separators, they have an inlet diverter to reduce the momentum of incoming stream and also to distribute liquid and gas within the separator. This kinetic energy reduction initiates phase separation inside a separator. Artificial gravity can be generated by the use of vortex tubes. A vortex tube is typically an elongated tube having a cylindrical interior wall that is preferably vertically mounted (M. West and Albert, 2003). Figure 6 below shows process flow in which inlet fluids is introduced from the horizontal inlet tube into vertically arranged vortex tubes.

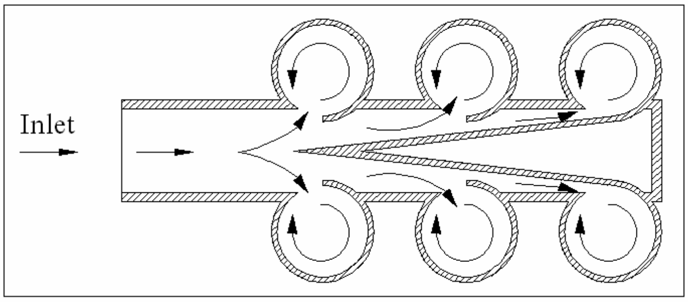


Figure 6: Horizontal Cross-sectional Plan View of Hydrocyclone Inlet Device.

Source: US Patent (M. West and Albert, 2003)

M. West and Albert (2003) stated that inlet fluids with high velocity will enter the tubes tangentially. The smooth transition creates centrifugal force that drives the heavier fluids to spin outward against the tube wall. The rapidly spinning fluids create a vortex within the tube where phase separation occurs with liquid leaving from bottom of the tubes and gas through the top as shown in Figure 7 below.

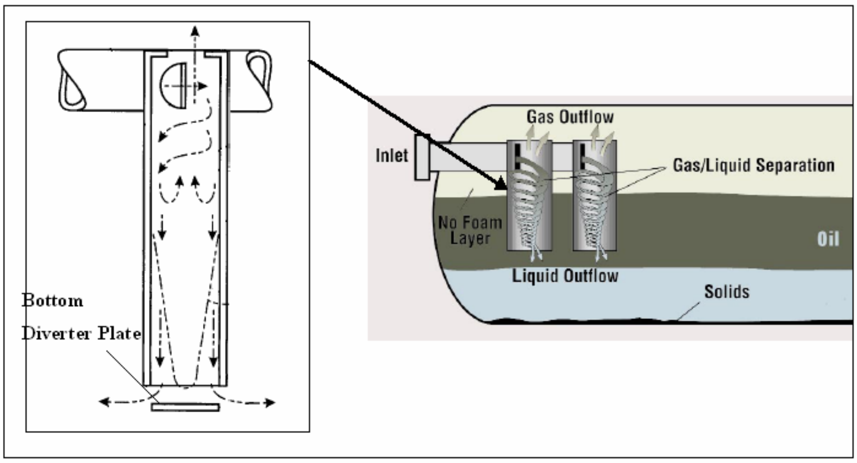


Figure 7: Side View of Hydrocyclone Inlet Device

Source: www.natco.com

Enough centrifugal force is created within these tubes to overcome surface tension and break down the emulsion. During operation, the tubes are partially immersed in liquid to prevent gas from blowing out of the vortex tube bottom openings. Spaced from the lower end of vortex tube is a bottom diverter plate that serves to spread the flow of liquid exiting from the vortex tube (Ernesto, 2008).

2.5.2 Benefits of Hydrocyclone Inlet Device

There are several advantages of using HID. This can be summarized as per below:

- Its enable high water cut marginal well to be developed
- Maximize the recovery of liquid hydrocarbon from fluid stream
- Greatly reduced retention time, thus increase speed of separation
- Can reduce or even eliminate emulsion problem
- Reduce emulsifier chemical expenditure
- Can be retrofitting to the existing conventional separator
- Use smaller vessel and lightweight as compared to conventional separator

2.5.3 Case Study: Installation of HID in V-1010 Separator at ANGSI Field.

As the project goes by, it has been found that Angsi Platform at the east coast of Peninsular Malaysia is applying the technology of HID to improve the separation process. The inlet device is installed at the inlet side of existing oil production separator, V-1010 which is a conventional type as shown in Figure 8 below.

Figure 8: Installation Process of HID in V-1010 Production Separator

Source: Installation of Inlet Device at Oil Production Separator at ANPG-A (Nazarudin, 2005)

The benefit gained is that the operation management does not have to install additional vessel to cater for additional flow rate. Basically, the problem at Angsi

Platform is that the production separator was initially design to separate 65 kbd of oil but the current production is more than the original design which is 115 kbd. By having hydrocyclone, the oil design capacity will be increase up to 145 kbd.

Table 3: Comparison between Before and After Inlet Device Installation

Product	Original Design, Without Inlet Device	With Inlet Device		
		Designed	Current Production	Remarks
Crude	65,000 bpd	145,000 bpd	115,000 bpd	Pipeline backpressure impedes flow
Gas	200 mmscfd	200 mmscfd	80 mmscfd	Gas is not yet reaching the design capacity
Water	35,000 bpd	35,000 bpd	3,000 bpd	Water is not yet reaching design capacity

Source: Installation of Inlet Device at Oil Production Separator at ANPG-A (Nazarudin, 2005)

By having HID in the separator, it helps to increase the separation capacity without additional vessel and major modification to the existing facilities. This is significant to Angsi Platform since the production separator is really big and it cannot be replaced by new separator. It is due to the replacement cost will be much higher than buying a new separator.

On top of that, the replacement of the vessel is very risky to conduct since it involved the offshore structure as well. Nazarudin (2005) stated that the cyclonic separation has been proven to achieve increase capacity by installing a tangential inlet device into existing vessel. The advantage of the inlet device is that it is a proven technology in Gulf of Mexico, USA, without additional vessel requirement.

Besides, it does not require additional footprint for the installation and use a minimal cost as compared to conventional production separator. As for new separator, sizes of vessel will be smaller with inlet device. The application of HID in Angsi oil production separator proves that this cyclonic separation technique is really works in terms of efficiency, reduce retention time, reduced emulsion problem and also increase the separation capacity (Nazarudin, 2005).

CHAPTER 3
METHODOLOGY

The methodology is important in order to complete the project successfully and follow the project timeline smoothly. See ***Appendix, Attachment 1: Project Timeline (Gantt-Chart)*** for reference.

3.1 FINAL YEAR PROJECT MILESTONE

There are two stages of project milestone which are project development and implementation. Both stages are run within one year time frame. The scopes of study during project development are feasibility study and design prototype. As for project implementation stage, the scopes of work are buying materials, construct prototype, design and conduct experiment, performing data analysis and evaluation of results. This project milestone is tabulated in the Table 4 below:

Table 4: Final Year Project Milestone

FYP I		FYP II	
January - March 2008	April - June 2008	July - September 2008	October - December 2008
Information Gathering from Online Resources, Journals and Books			
Feasibility Study			
Design Prototype			
	Buy Materials		
	Construct Prototype		
		Test Run	
	Design Experiment		
		Conduct Experiment	
			Data Analysis & Evaluate Results
PROJECT DEVELOPMENT	PROJECT IMPLEMENTATION		

3.2 PROCEDURES IDENTIFICATION

The strategy of completing this study is based on the workflow illustrated below:

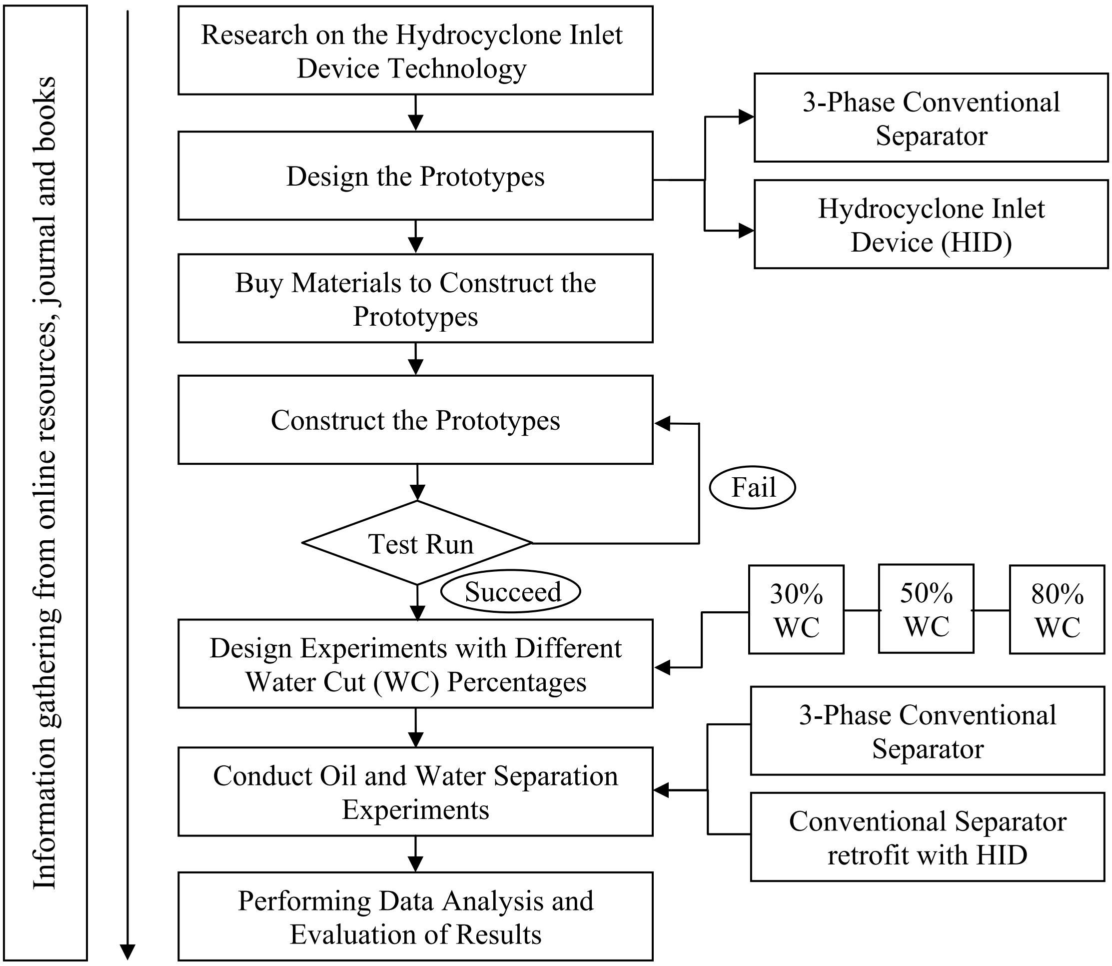


Figure 9: Methodology Process Flow Chart

3.2.1 Research on the Hydrocyclone Inlet Device Technology

All the research and data gathering is made from various sources such as internet, oil and gas magazines, latest journals and also experienced engineers at PCSB-PMO who are expert in process and facilities engineering.

Based on that, the author will be able to get the idea and basic understanding on the working principle of how hydrocyclone inlet device can enhance the oil and water separation. Besides, the author will be able to understand the advantages, disadvantages and also general applications of compact separation technology as a whole. As the project progresses, the research might still be continued for further improvement.

3.2.2 Design the Prototypes

In order to perform the study regarding how the cyclone effect may affect the oil and water separation process, the author has to design a prototype of:

i. 3-Phase Conventional Separator with Interface Level Controller design.
ii. Hydrocyclone Inlet Device (HID).

According to Ernesto (2008), almost all of the production separators are using conventional–interface level controller design. It is because this design can anticipated large oil flow rate and thick oil pad. In oil field, 3-phase production separator is always used with horizontal position rather than vertical position. Basically, horizontal orientation is well suited for oil segregation or oil-water separation where long residence time is required. Based on that, the author decided to design a basic prototype of 3-phase conventional separator in horizontal orientation using Interface Level Controller design.

The prototype has been designed in a way that it can be use to compare both techniques of separation between the cyclonic separation and conventional separation process. Both separation techniques will use the same vessel but use difference component at inlet of the vessel. To make the prototype become a conventional separator, an inlet diverter is added inside the basic construction of the vessel; whereas to improve the separation, hydrocyclone inlet device will be retrofitted at the fluid inlet as shown in figure 10 and 11 respectively. The designs of these prototypes are made by using CATIA software.

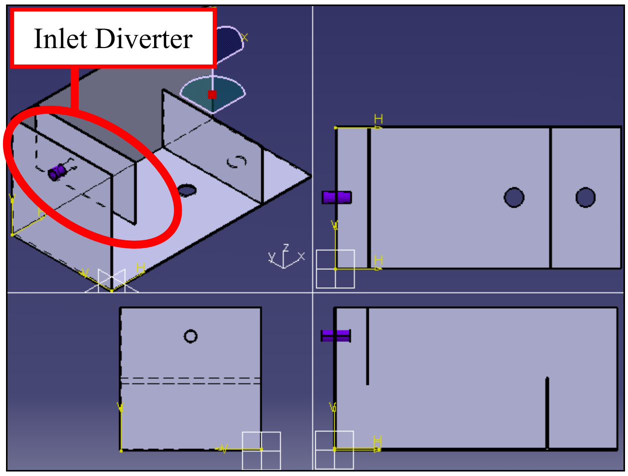


Figure 10: Multi-View of a Conventional Separator Prototype

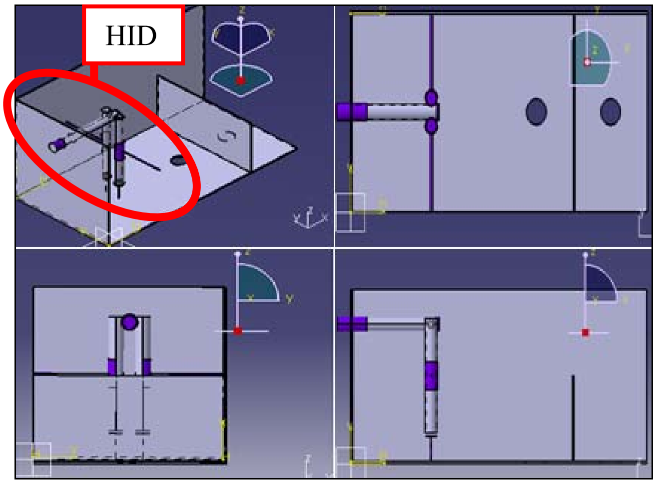


Figure 11: Multi-View of Separator retrofitted with HID Prototype

3.2.2.1 Design Assumptions

In this project, the author is designing the separator in a way that the pressure inside the separator is equal to the pressure at atmosphere since the author only focus on the oil and water separation process. As for the sizing of separator, it is actually based on the actual production separator at Angsi Platform, V-1010 (Nazarudin, 2005). For project purpose, the size is scale down to the ratio of 16 (ratio = 1:16). In other word, the prototype is 16 times smaller than the actual size. See ***Appendix, Attachment 2: P&ID of Angsi Oil Production Separator, V-1010*** for reference**.**

3.2.3 Buy Materials to Construct the Prototypes

At this stage, the author needs to consider several materials that need to buy in order to build the prototype. During this stage, it is important to first plan for the materials that need to buy to avoid buying the unused item. In fact, it will also help to use the budget given wisely. The raw materials that are required to construct the prototype are PVC tubes, perspex, pipes, pipe valves, connection pipe and steel. The functions of each of the material are shown in Tools and Equipments Required Section.

3.2.4 Construct the Prototypes

With the aim of studying how cyclonic effect can improve oil and water separation in high water cut production, the author need to construct prototypes of hydrocyclone inlet device and also 3-phase conventional separator. After the construction, the prototypes need to be test first prior to proceed with the experimental stage.

3.2.4.1 Test Run

The objective of the test run is to ensure that the prototypes are in a good condition with no defect. Since the vessel of the separator is constructed using perspex, leaking test need to be done to make sure that there is no leaking from the vessel. This is important because we are dealing with hydrocarbon liquid and water. The fact that hydrocarbon liquid is a corrosive agent makes it crucial to ensure that the vessel is able to handle the corrosive level of the hydrocarbon liquid.

Besides, the test was also performed to check how much volume capacity that the vessel is able to cope with. From the test run, the vessel is able to cater about 30 liters of liquid volume maximum. For safety reason, the author has decided to set the vessel's optimum design capacity at 20 liters volume. Figure 12 below shows the prototypes of conventional separator and separator retrofitted with HID respectively.

a) Conventional Separator Prototype	b) Separator retrofitted with HID

Figure 12: Prototypes

3.2.5 Design Experiment

The experiment is designed in a way that it neglected the fluid inlet properties such as pressure and temperature condition. The objective of the experiment is to look for the efficiency of oil and water separation process in terms of retention time. Thus, the experiment is designed to see how HID can handle production with high water ratio regardless of what type of oil used, pressure inside the vessel and fluid inlet properties. At reservoir, the fluid inlet is at high temperature. According to ideal gas law, PV=RT. Meaning at high temperature, the fluid will also be at high pressure since P is directly proportional to the T as long as the Volume is constant. At high temperature and pressure, composition of oil is different as compare to the surface condition. It is very difficult to achieve same fluid properties as the one in reservoir.

In the experiment, it is designed to separate a total volume of 20 liters of oil and water in the shaded vessel area as shown in Figure 13 below.

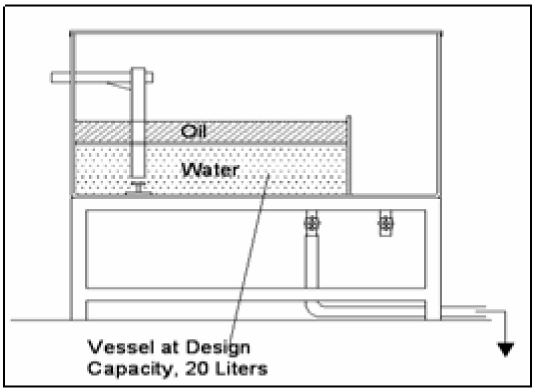


Figure 13: Vessel at Optimum Design Capacity of 20 Liters

Since the dimension used to construct prototype is in feet unit, it is required to convert 20 liters into cubic feet unit. The volume equivalent for 1 liter is equal to 0.03531 cubic feet. Therefore, 20 liters is equal to 0.7062 cubic feet. Figure 14 shows the dimension of volume that will be used in experiment.

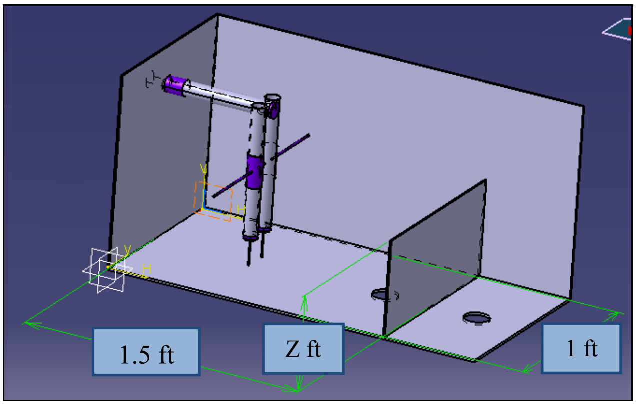


Figure 14: Dimension of Volume Used in the Experiment

$$1.5 \text{ ft} \times 1 \text{ ft} \times Z \text{ ft} = 0.7062 \text{ cuft} = 20 \text{ liters}$$

$$Z = 0.4708 \text{ ft} = 14.35 \text{ cm} \qquad \text{where } 1\text{ft} = 30.48 \text{ cm}$$

Assuming that fluid at design capacity of 20 liters is equal to 14.35 cm thickness.

$$14.35 \text{ cm} \rightarrow 20 \text{ liters}$$

$$1 \text{ cm} = 20/\ 14.35$$

$$1 \text{ cm} = 1.394 \text{ liters}$$

Therefore, 1 cm thickness ≈ 1.4 liters

The readings of oil, emulsion and water pad thickness were taken every minute in each test to get the result of retention time. To determine volume of oil and water, the readings of both pad thickness need to convert into liter unit by multiplying with 1.394 value factor.

3.2.6 Conduct Experiment

3.2.6.1 Design Experimental

Experiments will be conducted once the prototypes are prepared. The conventional and improved separation tests are performed in a transparent model of a horizontal separator made of perspex. The conventional separator internals were limited to a plate of inlet diverter and an oil overflow weir. As for the improvement of the separation, HID and bottom diverter plate are retrofitted with the same vessel as the conventional separator. The layouts of experimental setup for both conventional and separator with HID are shown in figure 15 and 16 respectively.

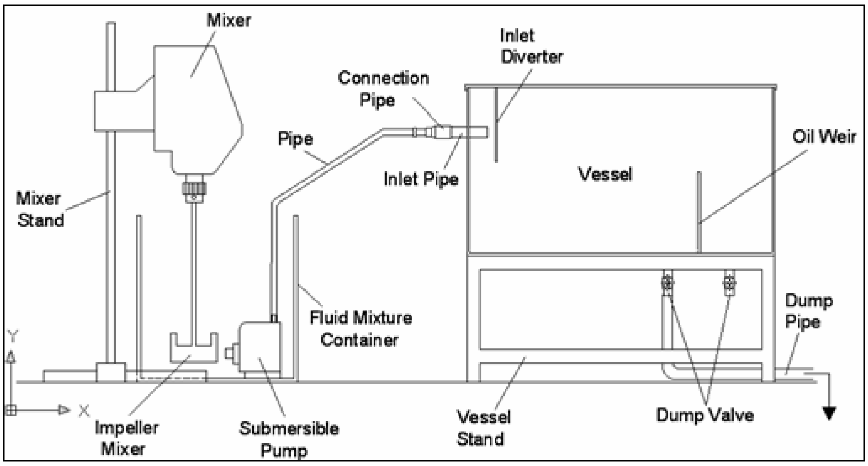


Figure 15: Experimental Layout for Conventional Separator

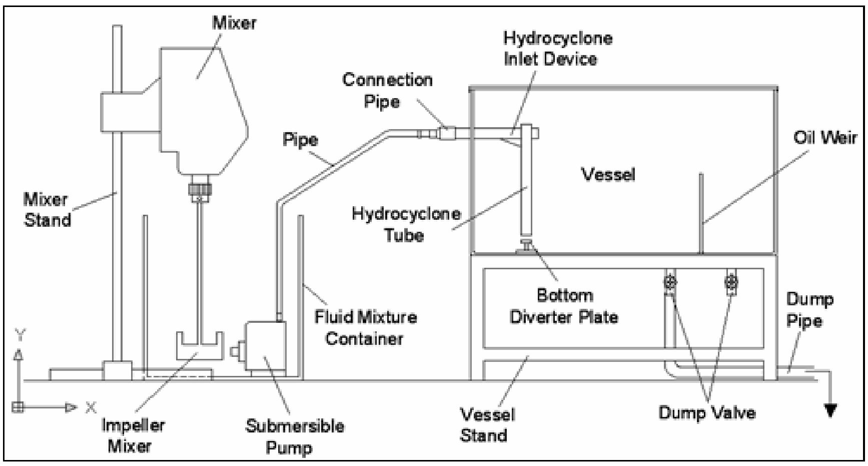


Figure 16: Experimental Layout for Separator with Hydrocyclone Inlet Device

The model oil used in the tests was Diesel oil, which give yellow-brown clear oil with a viscosity of approximately 20 cp. A total volume of 20 liters of oil and water were mixed together in the fluids mixture container. For example, the experiment for test 1 is to run with 30% water cut; which means 6 liters of water were added with 14 liters of oil in the container. These fluids were then mixed together using a static mixer at 80 rpm speed. Inside the container, there is a submersible pump to pump and deliver fluids mixture to the separator at 1500 m^3/h flow rate. The test matrix consist a total of 6 single tests performed where 3 tests for each conventional and improved separation experiment. The three tests are basically referred to the water cut percentage which is 30%, 50% and 80% respectively as shown in the Table 5.

Table 5: Number of Test per Experiment

Test No.	Water Cut Percentages, (%)	Volume of Water, (ℓ)	Volume of Oil, (ℓ)
1	30	6	14
2	50	10	10
3	80	16	4

Oil, emulsion and water pad thickness values were measured and recorded for every minute during each test until the values are constant for at least twice to get the accurate retention time. Retention time is time taken for phases to combine together. Below shows the parameters involved in the experiments:

Table 6: Parameters Involved

Variable Parameters	**Constant Parameters**
• Percentage of water cut, W_c (%) • Retention time, t_r (s) • Oil Pad Thickness, P_o (mm) • Emulsion Thickness, P_e (mm) • Water Thickness, P_w (mm) • Efficiency of Separation, ε (%) • Volume of Oil Inlet, V_{Oinlet} (ℓ) • Volume of Water Inlet, V_{Winlet} (ℓ)	• Inlet Flowrate, Q_{inlet} = 416.7 ℓ/min • Total Volume Fluid, $\sum V_{fluid}$ = 20 ℓ • Motor Speed of Mixer = 80 Rpm • Type of oil = Diesel Oil • Temperature and Pressure Conditions: - Ambient Temperature = 27 ◦C - Room Pressure = 1 atm or = 14.7 psia

To be simplified, the experimental design can be summarized as per below:

i. The model oil used in the tests is Diesel Oil.
ii. Experiments operated at atmospheric pressure & ambient temperature.
iii. 2 experiments will be conducted using conventional separator & separator retrofitted with HID
iv. 3 same tests are run according to the water cut percentages.
v. A total volume of 20 liters of oil & water were mixed together in the fluid mixture container before flowing it to the vessel.
vi. These fluids were mixed together using static mixer at 80 rpm speed.
vii. Then a submersible pump will deliver the fluid mixture to the separator at 417 ℓ / min flow rate.
viii. Oil, emulsion and water pad thickness values were measured every minute during each test until its constant to get separation time.
ix. The types of collected data are the comparison of oil separation time, volume of oil recovery, emulsion pad reduction at 1st minute of separation and the efficiency of separation.
x. The separated oil and water are then dumped to wasted fluids container.

The details of experiment including the experiment's procedures and experimental layout are being attached at ***Appendix Section, Attachment 3: Experimental.***

3.2.7 Performing Data Analysis and Evaluation of Results

Data analysis is performed once the experiment results are obtained. Based on that, it can be shown that the cyclonic effect can improve the oil and water separation. The evaluation of results is based on collected data from the comparison of oil separation time, volume of oil recovery, emulsion pad reduction at 1st minute of separation and the efficiency of separation between the conventional separator and separator retrofitted with HID.

Based on the retention time taken for both separation techniques, the correlation of retention time to water cut percentages is performed. Using this correlation, retention time taken for other water cut percentages can be predicted for both conventional separator and separator with HID. Based on that, the performance of both separation techniques can be compared to see which technique separated faster.

3.3 TOOLS / EQUIPMENT REQUIRED

3.3.1 Chemical and Mechanical Tools Required for Experiment

For this project to accomplish successfully, it requires both chemical and mechanical tools as shown in Table 7. Figure 17 shows the picture of tools and equipment required to conduct the experiment.

Table 7: Chemical and Mechanical Tools Required

Chemical's Substances Required	
Chemical's Substance	**Function**
Diesel Oil	Act as the Crude oil from the reservoir
Water	As the water that mix with the hydrocarbon fluid
Mechanical Equipment Required	
Material	**Function**
PVC Tubes	Hydrocyclone Inlet Device
Perspex	Inlet Diverter, Bottom Diverter Plates, Weir and Vessel
PVC Pipes	Connection Pipe, Inlet and Outlet Pipes
Pipe Valves	To dump the outlet fluid
Steel	To serve as the stand to support the vessel
Submersible Pump	To pump a mixture of oil & water to the separator
Measurement Beaker	To measure the quantity of inlet fluid to be use in the experiments
Container	To fill the mixtures of oil and water To contain the diesel oil fluid To contain the wasted fluids mixture
Mixer	To mix-up the oil and water
Power Supply	To provide power for the mixer and pump to run

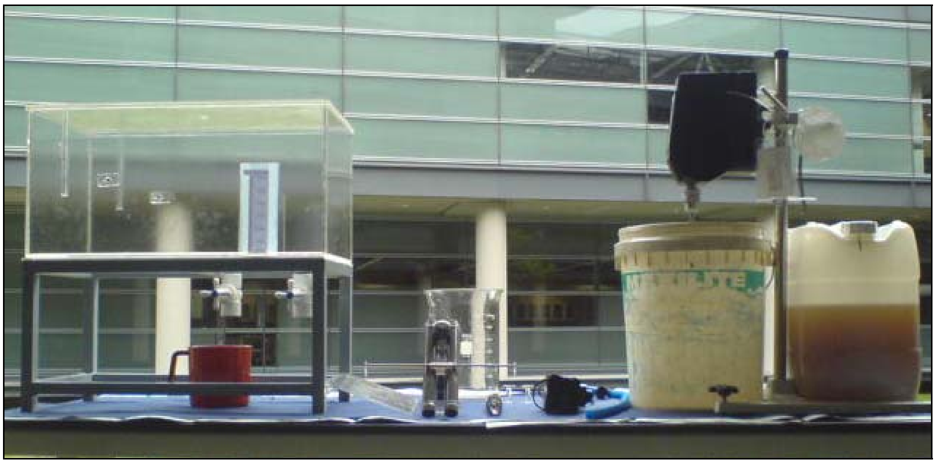


Figure 17: Tools and Equipment Required

3.3.2 Software Required for Designing Prototypes

AUTOCAD and CATIA software are required to design the prototypes of 3-phase conventional separator and hydrocyclone inlet device in 2 and 3-Dimension respectively. This is essential to get a better overview in order to construct the prototypes.

Figure 18: Software used for Designing Prototypes

CHAPTER 4

RESULT AND DISCUSSION

This chapter presents comparison of the oil and water separation using between the conventional separator and separator retrofitted with HID models. Comparisons are made for the water cut percentages; from low to high water cut production (30%, 50%, and 80%) to the oil separation time, volume of oil recovery, emulsion pad reduction and efficiency of separation.

4.1 EXPERIMENTAL RESULTS

4.1.1 Test Result for 30% Water Cut

Table below shows the test results from the oil and water separation experiment for 30% water cut using both conventional separator and separator with HID.

Table 8: Test result of Oil and Water Separation for 30% Water Cut

TEST NO.	Percentage of water cut, %	Volume of inlet oil, ℓ	Volume of inlet water, ℓ	Total Volume Outlet, ℓ
1	30%	14 ℓ	6 ℓ	18.5 ℓ

Separation of Oil and Water Using Conventional Separator							
Time Taken (every minute until it settle)	1	2	3	4	5	6	7
Oil Pad Thickness, cm	8.9	8.9	9.0	9.1	9.1	9.3	9.3
Emulsion Pad Thickness, cm	1.2	0.8	0.6	0.5	0.3	0.1	0.1
Water Pad Thickness, cm	3.2	3.6	3.7	3.7	3.9	3.9	3.9
Separation of Oil and Water Using Hydrocyclone Inlet Device (HID)							
Time Taken (every minute until it settle)	1	2	3	4	5	6	7
Oil Pad Thickness, cm	9.2	9.3	9.4	9.5	9.5	9.5	9.5
Emulsion Pad Thickness, cm	0.6	0.3	0.2	0.1	0.1	0.1	0.1
Water Pad Thickness, cm	3.5	3.7	3.7	3.7	3.7	3.7	3.7

In this test, 14 liters oil and 6 liters water represented a mixture of crude oil fluid with 30% water cut with the total volume of 20 liters. With 30% of water cut, the test is corresponding to a green field at its constant production rate which is also known as plateau period. By means of 30% of water in production, it is consider as low water cut which is acceptable in the oil and gas industry. However as shown in the table, only 18.5 liters of fluids mixture is been transferred to the vessel. The same phenomenon goes to every test conducted. The explanation for this matter will be discussed in Experimental Limitations Section.

To get a better picture of the result from Table 8, a graph of oil, emulsion and water pad thickness versus time taken between conventional separator and separator with HID can be plotted as shown in Figure 19, 20, and 21 respectively.

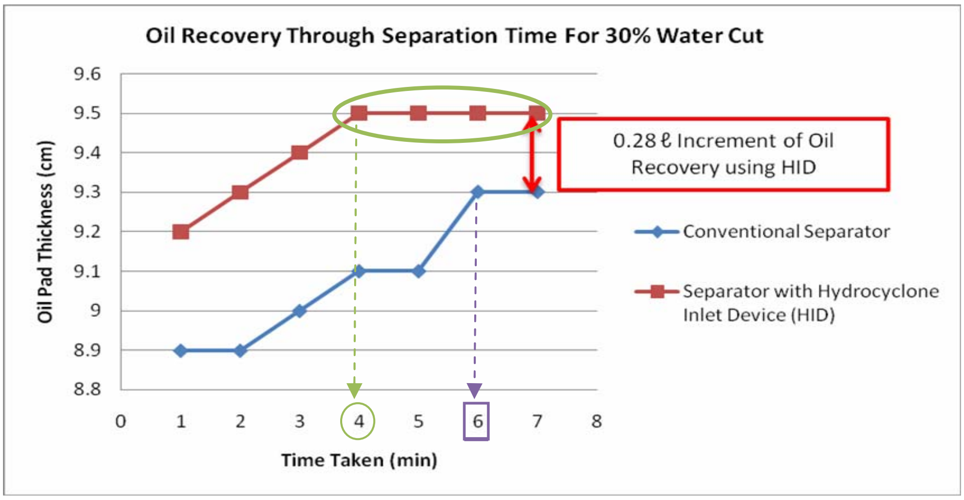


Figure 19: Comparison of Oil Pad Thickness between Conventional and HID

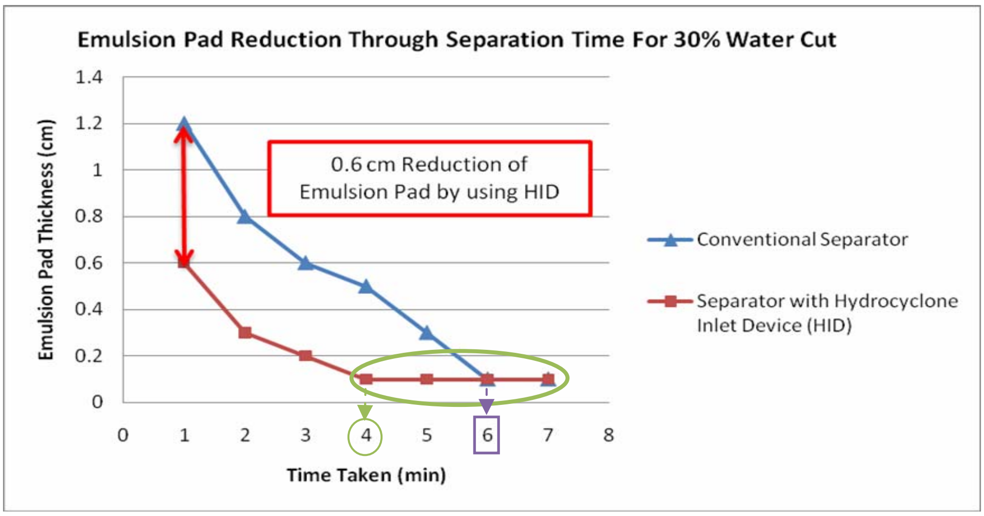


Figure 20: Comparison of Emulsion Thickness between Conventional and HID

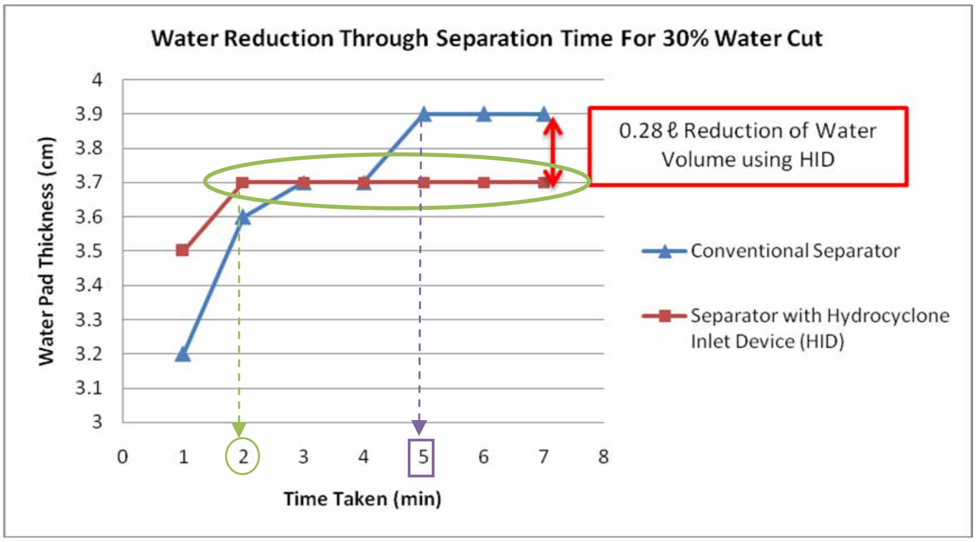


Figure 21: Comparison of Water Pad Thickness Between Conventional and HID

Figure 19 shows that separator retrofitted with HID has more oil pad thickness value than the conventional separator by 0.2 cm. Since the ratio of 1 cm thickness is equal to 1.4 liters, the usage of HID has improved the hydrocarbon separation by increasing the oil recovery by 0.28 liters.

This Figure 20 shows that the emulsion pad thickness is greatly reduced at the early stage of separation by using HID. At 1st minute of separation, the emulsion thickness for conventional separator is 1.2 cm and 0.6 cm in separator with HID. This shows that the emulsion thickness is reduced 0.6 cm by using HID. This may result in reducing the cost for demulsifier agent in the production separator.

Noted that the reading of the oil and emulsion pad thickness is constant starting at 4th minute for separator retrofitted with HID, and at 6th minute for conventional separator. These indicated that both of the separators have reached their oil retention time at respective minute. Thus, by using HID, the oil retention time is reducing by 2 minutes.

Figure 21 shows the improvement of water separation by using HID in the separator as compared to conventional separator since it reduced the volume of water in by 0.28 liters. (Difference of 0.2 cm water thickness.) This reduction of water volume has resulted in increasing the volume of oil separated in which shows that HID has improved the oil and water separation. From the graph, we can see that separator with HID has reached water retention time at 2nd minute, while conventional separator is at 5th minute. Thus, the water retention time is reduced by 3 minutes.

For information, oil retention time is a time taken for the oil to coalesce into droplet sizes sufficient to fall while water retention time is a certain amount of water storage needed to assure that most of the large droplets of oil entrained in the water have enough time to coalesce and rise to the oil-water interface. By reducing the oil and water retention time, the speed of separation process will be increase which result in increasing the oil separation capacity.

From these graphs, it can be concluded that the usage of HID in conventional separator help to improve the hydrocarbon separation at low water cut production.

4.1.2 Test Result for 50% Water Cut

Table below shows the test results from the oil and water separation experiment for 50% water cut using both conventional separator and HID.

Table 9: Test result of Oil and Water Separation for 50% Water Cut

TEST NO.	Percentage of water cut, %	Volume of inlet oil, ℓ	Volume of inlet water, ℓ	Total Volume Outlet, ℓ		
2	50%	10 ℓ	10 ℓ	18.5 ℓ		
Separation of Oil and Water Using Conventional Separator						
Time Taken (every 2 minutes until it settle)	1	3	5	7	9	11
Oil Pad Thickness, cm	6.1	6.2	6.3	6.3	6.4	6.4
Emulsion Pad Thickness, cm	0.8	0.5	0.3	0.2	0.1	0.1
Water Pad Thickness, cm	6.4	6.6	6.7	6.8	6.8	6.8
Separation of Oil and Water Using Hydrocyclone Inlet Device (HID)						
Time Taken (every minute until it settle)	1	3	5	7	9	11
Oil Pad Thickness, cm	6.4	6.5	6.6	6.7	6.7	6.7
Emulsion Pad Thickness, cm	0.5	0.3	0.2	0.1	0.1	0.1
Water Pad Thickness, cm	6.4	6.5	6.5	6.5	6.5	6.5

In this test, both 10 liters oil and water are represented a mixture of crude oil fluid with 50% water cut with the total volume of 20 liters. With 50% of water cut, this test is corresponding to a field at the early stage of decline period where the production rate is starting to decline due to high water cut. By means of 50% water in production, it is consider as a caution level as it is near to high water cut level.

The production is consider to reach high water cut when there is 60% and above of water in its production. The increase of water cut will require the production separator to separate more water from its production to get the crude oil. This separated water will be treated prior to discharge it to the sea with the concentration of 40 ppb (parts per billion) as referring to PETRONAS water quality standard. These water treatments spend a lot of operation expenditure to the platform. Hence, by having HID it helps to reduce amount of water to be treated and indirectly save the budget of chemical expenditure for water treatment.

To get a better picture of the result from Table 9, a graph of oil, emulsion and water pad thickness versus time taken between conventional separator and separator with HID can be plotted as shown in Figure 22, 23, and 24 respectively.

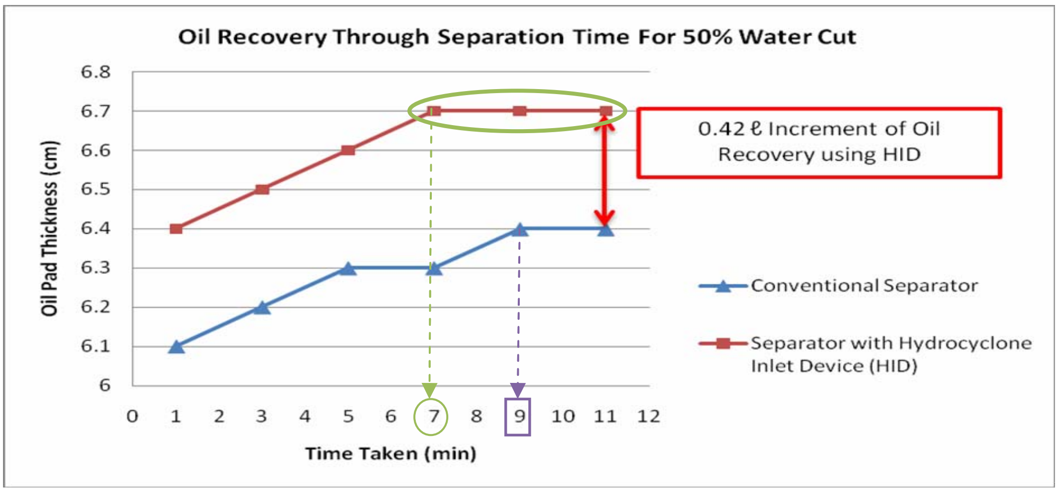


Figure 22: Comparison of Oil Pad Thickness between Conventional and HID

Figure 22 shows that separator retrofitted with HID has more oil pad thickness value than the conventional separator by 0.3 cm. Since the ratio of 1 cm thickness is equal to 1.4 liters, the usage of HID has improved the hydrocarbon separation by increasing the oil recovery by 0.42 liters.

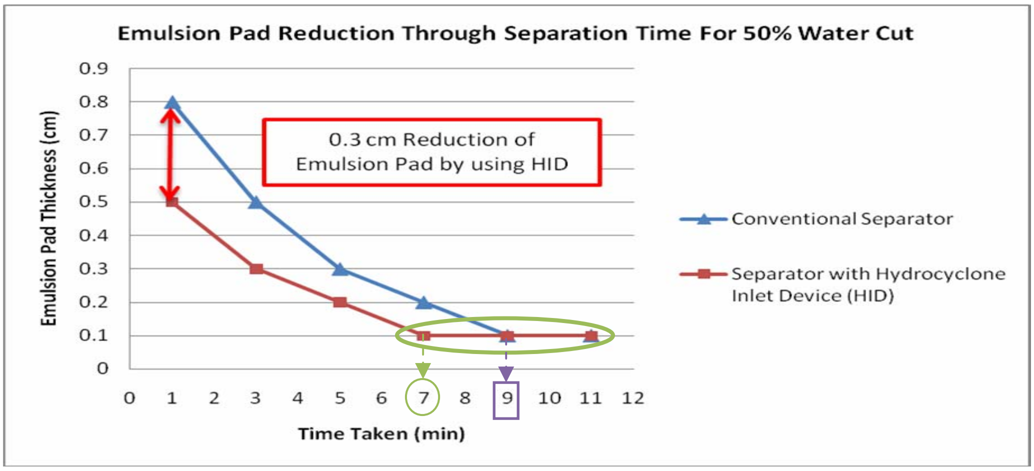


Figure 23: Comparison of Emulsion Thickness between Conventional and HID

Figure 23 shows that the emulsion thickness is reduced in 0.3 cm at the early stage of separation by using HID. However, the differences in emulsion thickness is getting smaller until both emulsion thickness reached 0.1 cm. Noted that the reading of the oil and emulsion pad thickness is constant starting at 7th minute for separator using HID, and at 9th minute for conventional separator. These indicated that both of the separators have reached their oil retention time at respective minute. Thus, by using HID, the oil retention time is reducing by 2 minutes.

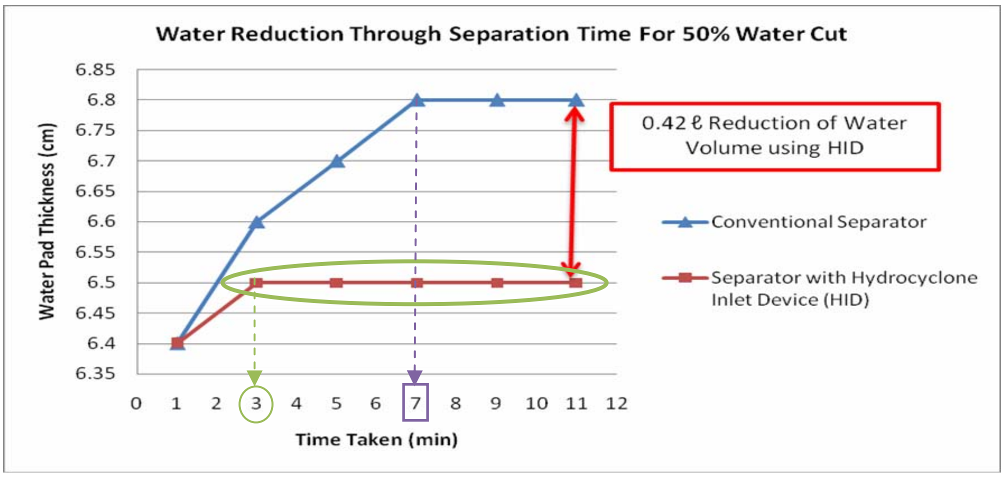


Figure 24: Comparison of Water Pad Thickness between Conventional and HID

Figure 24 shows the improvement of water separation by using HID in the separator as compared to conventional separator since it reduced the volume of water by 0.42 liters (difference of 0.3 cm water thickness). This reduction of water volume has resulted in increasing the volume of oil separated in which shows that HID has improved the oil and water separation.

From Figure 24, we can see that separator with HID has reached water retention time at 3-minute, while conventional separator is at 7-minute. Thus, the water retention time is reduced by 4 minutes. By reducing the oil and water retention time, the speed of separation will be increase which result in increasing the oil separation capacity.

From these graphs, it can be concluded that the usage of HID in conventional separator help to improve the hydrocarbon separation at medium water cut production.

4.1.3 Test Result for 80% Water Cut

Table below shows the test results from the oil and water separation experiment for 80% water cut using both conventional separator and HID.

Table 10: Test result of Oil and Water Separation for 80% Water Cut

TEST NO.	Percentage of water cut, %	Volume of inlet oil, ℓ	Volume of inlet water, ℓ	Total Volume Outlet, ℓ
3	80%	4 ℓ	16 ℓ	18.5 ℓ

Separation of Oil and Water Using Conventional Separator											
Time Taken (every 2 minutes until it settle)	1	3	5	7	9	11	13	15	17	19	21
Oil Pad Thickness, cm	1.0	1.2	1.4	1.5	1.6	1.7	1.8	1.9	2.1	2.2	2.2
Emulsion Pad Thickness, cm	1.8	1.6	1.3	1.1	0.9	0.8	0.6	0.4	0.2	0.1	0.1
Water Pad Thickness, cm	10.5	10.5	10.6	10.7	10.8	10.8	10.9	11.0	11.0	11.0	11.0
Separation of Oil and Water Using Hydrocyclone Inlet Device (HID)											
Time Taken (every 2minutes until it settle)	1	3	5	7	9	11	13	15	17	19	21
Oil Pad Thickness, cm	1.6	1.7	1.8	2.0	2.2	2.4	2.5	2.5	2.5	2.5	2.5
Emulsion Pad Thickness, cm	1.2	1.0	0.8	0.6	0.4	0.2	0.1	0.1	0.1	0.1	0.1
Water Pad Thickness, cm	10.5	10.6	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7

In this test, 4 liters oil and 16 liters water represented a mixture of crude oil fluid with 80% water cut with the total volume of 20 liters. With 80% of water cut, this test is corresponding to a brown field at the end of decline period. By means of 80% water in production, it is consider as high water cut which is undesirable since the platform produced more water instead of crude oil. In this case, more water needs to be treated before discharge to the sea as compare to production with 50% water cut.

The using of HID was proven to improve the oil separation capacity and increased the speed of separation at Angsi Platform which is having production with low water cut. However, the usage of this device has not been proven in any brown field with high water cut production. Thus, this test is the focus of the experiment in order to observe the effect of HID in high water cut production.

From the result shown in Table 10, it shows that HID does improve the hydrocarbon separation as well. To get a better picture of the result from Table 10, a graph of oil, emulsion and water pad thickness versus time taken between conventional separator and separator retrofitted with HID can be plotted as shown in Figure 25, 26, and 27 respectively.

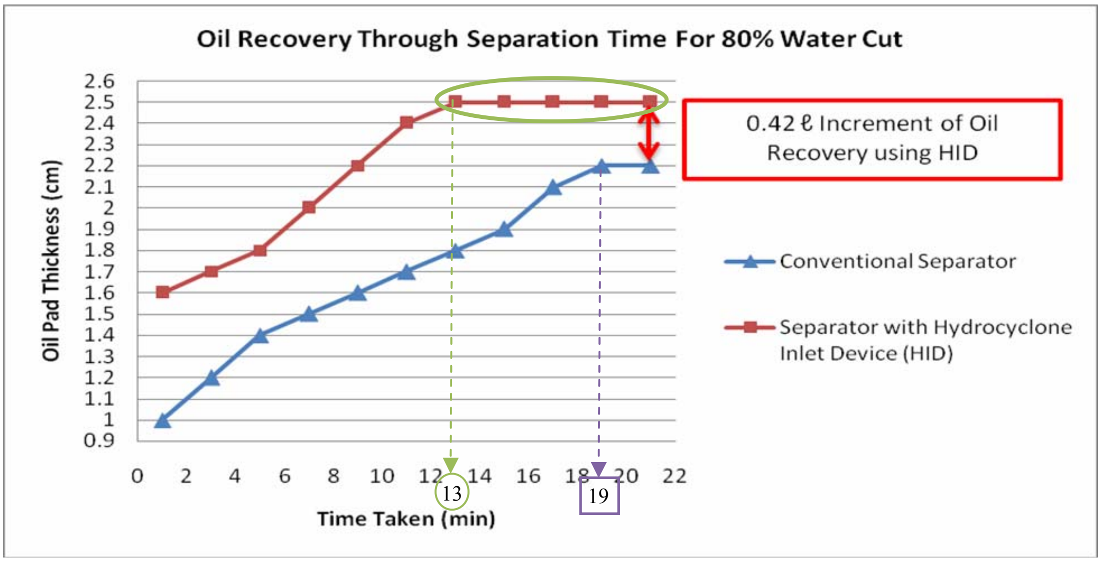


Figure 25: Comparison of Oil Pad Thickness between Conventional and HID

Figure 25 shows that separator retrofitted with HID has more oil pad thickness value than the conventional separator by 0.3 cm. Since the ratio of 1 cm thickness is equal to 1.4 liters, the usage of HID has improved the hydrocarbon separation by increasing the oil recovery by 0.42 liters.

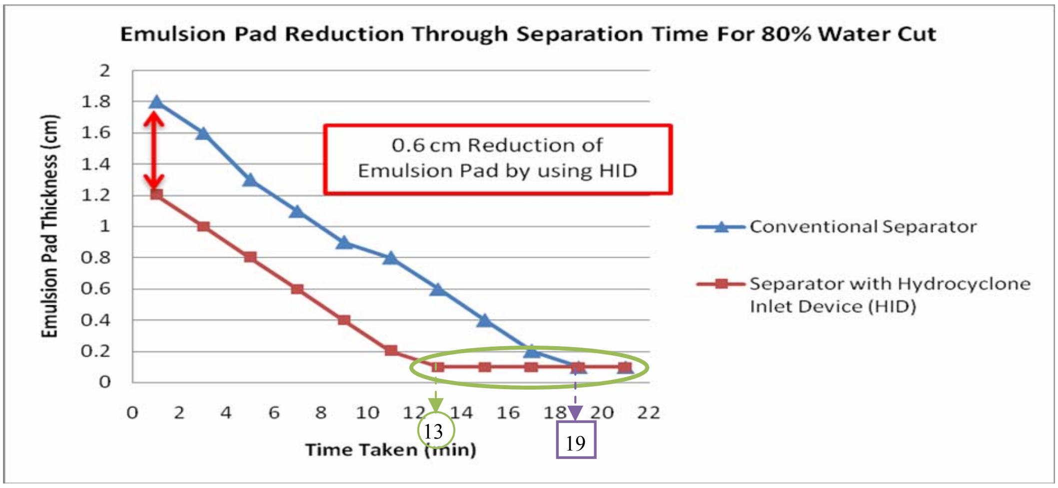


Figure 26: Comparison of Emulsion Thickness between Conventional and HID

Figure 26 shows that the emulsion thickness is reduced by 0.6 cm at the early stage of separation by using HID. Noted that the reading of the oil and emulsion pad thickness is constant starting at 13th minute for separator using HID, and at 19th minute for conventional separator. These indicated that both of the separators have reached their oil retention time at that respective minutes. Thus, by using HID, the oil retention time is reducing by 6 minutes.

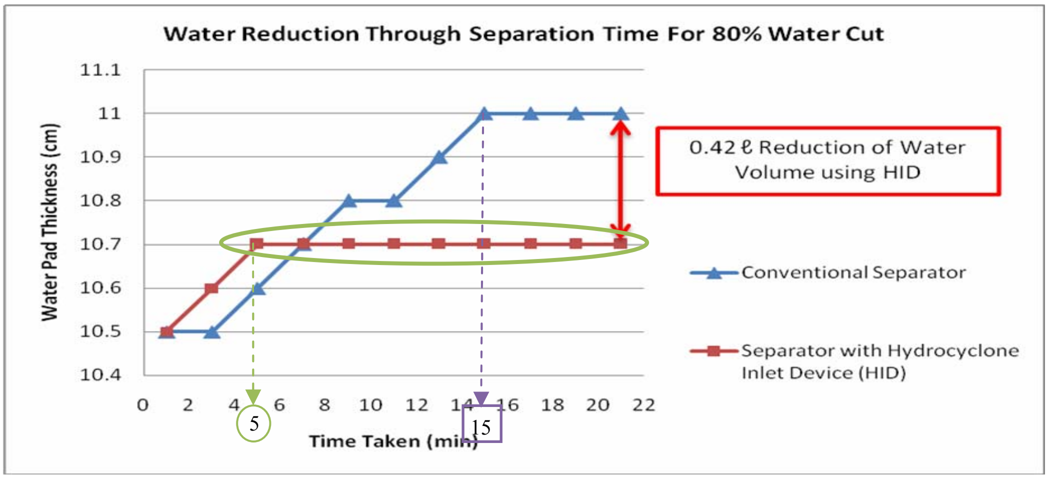


Figure 27: Comparison of Water Pad Thickness between Conventional and HID

Figure 27 shows the improvement of water separation using HID in the separator as compared to conventional separator since it reduced the volume of water by 0.42 liters (difference of 0.3 cm water thickness). This reduction of water volume has resulted in increasing the volume of oil separated in which shows that HID has improved the oil and water separation.

Figure 27 shows that the separator retrofitted with HID has reached water retention time at 5th minute, while conventional separator is at 15th minute. Thus, water retention time is reduced by 10 minutes. The reduced in oil and water retention time make separation speed increased which resulted in increasing oil separation capacity.

From these graphs, it can be concluded that the usage of HID in conventional separator help to improve the hydrocarbon separation at high water cut production.

4.1.4 Summary Result of the Experiment

Table below shows the overall test results from the oil and water separation experiment for 30%, 50% and 80% of water cut using both conventional separator and separator retrofitted with HID.

Table 11: Summary of Oil and Water Separation Experiment

TEST NUMBER	1		2		3	
Percentage of Water Cut, %	30% (Low WC)		50% (Medium WC)		80% (High WC)	
SEPARATION TECHNIQUE*	CONV.	HID	CONV.	HID	CONV.	HID
Oil Retention Time, min	6	4	9	7	19	13
Water Retention Time, min	2	5	3	7	5	15
Oil Pad Thickness, cm	9.3	9.5	6.4	6.7	2.2	2.5
Volume of Oil Recovery, ℓ	12.96	13.24	8.92	9.34	3.07	3.49
Emulsion Pad Reduction at 1st minute of Separation, cm	1.2	0.6	0.8	0.5	1.8	1.2
Efficiency of Hydrocyclone Separation, %**	33.33%		22.22%		31.58%	

*Conv. is refer to Conventional Separator while HID is refer to Hydrocyclone Inlet Device
** Efficiency is based on reduced Oil Retention Time

Table 11 shows the summary of results from all the tests that have been conducted; from a low water cut to high water cut. This is to investigate how effective the cyclonic effect from HID is capable to improve the oil and water separation regardless of water cut percentages. The level of effectiveness is measure in term of the improvement in oil recovery, the capability of emulsion reduction and oil and water retention time reduction in order to increase the speed of separation.

Result I: Improvement in Oil Recovery

The objective of any oil and gas industry is to recover as much oil as the field can produce. The existence of Hydrocyclone Inlet Device (HID) helps the mature field with declining production rate to maximize the recovery of liquid hydrocarbon from fluid stream through improved separation. Figure 28 shows improvement of oil recovery in oil and water separation by retrofitting HID into conventional separator. To get a better picture, the author has compared result of oil recovery between conventional separator and separator with HID with respect to water cut percentages.

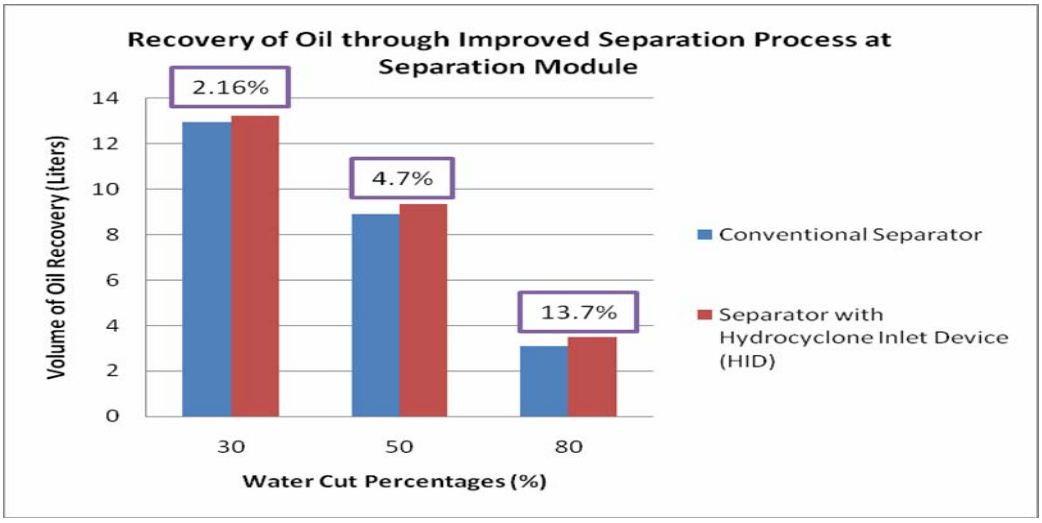


Figure 28: Comparison of Oil Recovery between Conventional Separator and Separator with HID in Different Water Cut Percentages

Figure 28 shows that the usage of HID in conventional separator has improved the separation process by maximizing the oil recovery with the increment of 2.16%, 4.7% and 13.7% for 30%, 50% and 80% of water cut percentages respectively. It can be proven that HID can improve the oil recovery even in high water cut percentage. In fact, the increment of oil recovery at high water cut is the largest as compare to the rest. This shows that HID greatly help in maximizing the oil recovery at mature field with high water cut. The increasing in oil recovery will increase the field’s profit since the amount of crude oil that can be sell increase.

Result II: Improvement in Handling Emulsion Problem

The present of emulsions is one of the production problems. It can be troublesome in the operation of 3-phase separators since the settling time required to achieve an acceptable separation may be longer than required to separate the gas. After certain duration of time, an accumulation of emulsified materials will form at the water and oil interface. This accumulation will also decrease the effective oil or water retention time in the separator, which will decrease the water-oil separation efficiency (M. Stewart, 2002). Usually, a demulsifier agent will be used to control or reduce the emulsion thickness and this chemical agent is costly to the platform.

From the result of the experiment, it has been shown that the usage of HID in the separator help to reduce the emulsion pad thickness at the early stage of separation process. This can be shown in Figure 29. To get a clear picture, the author has compared results of emulsion thickness between conventional separator and separator with HID with respect to water cut percentages.

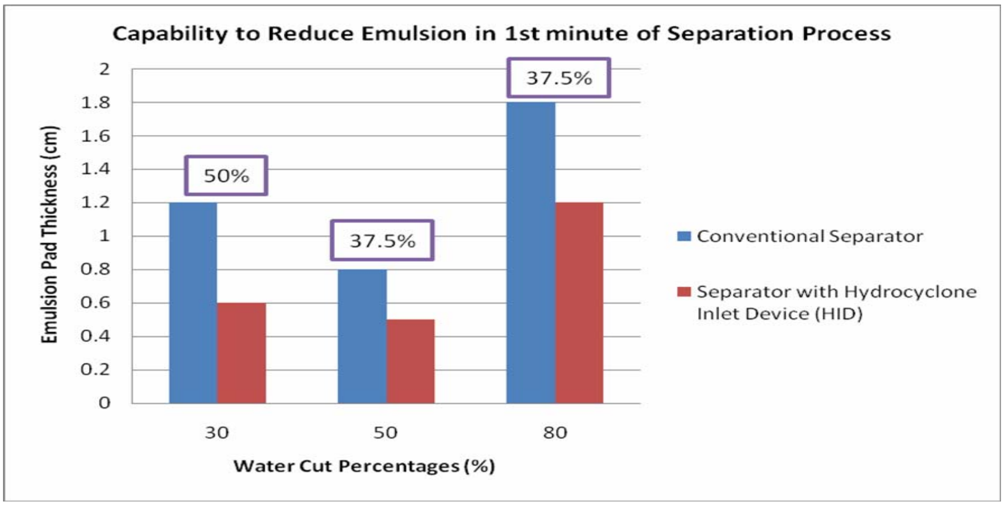


Figure 29: Comparison of Emulsion Pad Thickness between Conventional Separator and Separator with HID in Different Water Cut Percentages

Figure 29 shows the emulsion pad thickness collected at the 1st minute of separation for all 3 tests performed in both conventional separator and separator retrofitted with HID. Test 1 with 30% water cut shows the highest emulsion thickness reduction with 50% decrease as compare to conventional separator. Both test 2 and 3 with 50% and 80% water cut respectively show the same percentages of emulsion reduction with 37.5% decrease as compare to conventional separator.

From the experiment conducted, it has been discovered that the HID is able to breaks down the emulsion formation using the centrifugal forces from the cyclonic separation. From Natco website, it stated that velocity which is created in the inlet manifold is introduced into the vortex tube tangentially. The smooth transition creates centrifugal force that drives the heavier fluids to the tube wall.

Enough centrifugal force is created within these tubes to overcome surface tension and break down the emulsion. This will improve the separation efficiency of the separator and even can cut the cost by reducing the use of chemicals. As a conclusion, HID improved the separation by reducing the emulsion thickness. As the effect of emulsion reduction, it helps to reduce the oil and water retention time and thus increase the speed of separation and its efficiency.

Result III: Improvement in Increasing the Speed of Separation

The speed of separation plays an important role to improve the oil recovery. To increase the speed of separation, it depends on oil retention time. Retention time is a certain amount of time required to ensure that the water, oil and gas have separated within each other by mean of gravity and reached their equilibrium phase at prevailing temperature and pressure condition (Mary, 1998). If the residence time is not enough, gas has no time to rise from gas–oil interface.

The conventional separator therefore relies on an adequate retention time to ensure an efficient and clean separation of its oil and water phases. However, this retention time poses a limit to increase additional flow rate or production for fields undergoing production enhancement activities. This problem always occurred in a green field with low water cut. Hence, by having HID, it helps to increase the separation capacity without additional vessel and major modification to the existing facilities.

The problem always occurred in mature field with high water cut production is insufficient of oil retention time during the separation process. The insufficient of retention time for oil droplets to settle out from the water phase will lead to a relatively high amount of oil-in-water carried over to the produced water treatment system. This problem can be solved by using the HID.

It is because HID will make the separation occurs more rapidly so that the separator will have enough time to separate the oil, water and gas to its equilibrium phases. For the separation to occur rapidly, the separator needs to increase the speed of separation by reducing the retention time. These show how important the retention time is to improve the efficiency of hydrocarbon separation. From the experiments conducted, the results show that the retention time can be reduced by using the HID in the separator regardless of water cut percentages.

Figure 30 presents the correlation of retention time to water cut percentage. Using this graph, we can predict the retention time according to the water cut percentages.

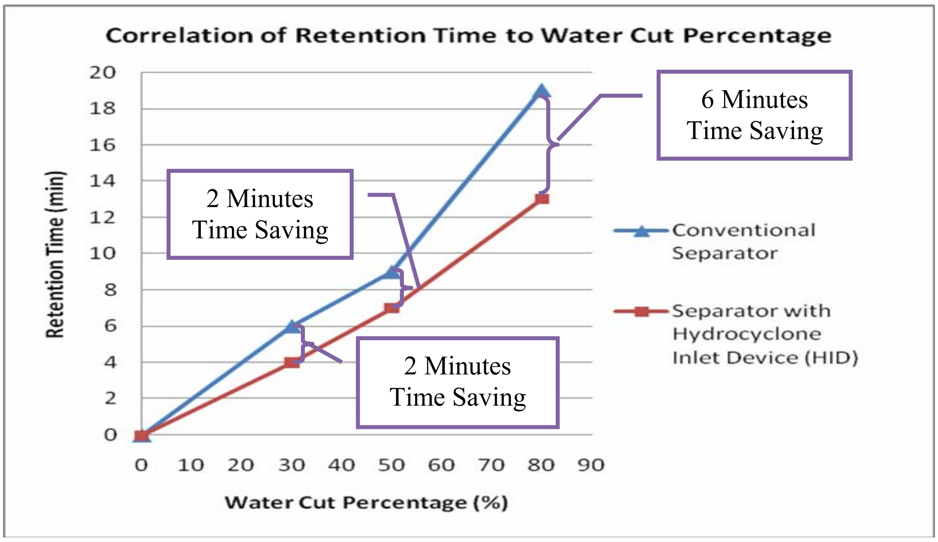


Figure 30: Correlation of Retention Time to Water Cut Percentages

From the graph shown, the required retention time was found to increase with the increasing of water cut percentages. Somehow, the usage of HID helps to reduce the retention time required no matter how much the water cut percentages is in its production.

The explanation is that the HID is an inlet device that uses the centrifugal force to separate fluids. The use of centrifugal force can affect the flow patterns to separate immiscible phases of different densities. In fact, this centrifugal action can somehow increased the affective force of gravity from the existing separator and this will make the separation occurs more rapidly. This is supported by the fact that the centrifugal force is thousand times greater than gravity force (Arnold and Ferguson, 1999).

Therefore it will increase the speed of separation by reducing the retention time required. Figure 30 prove that the usage of HID in existing separator is compatible to all field regardless of its water cut percentages since it help to reduce the required retention time. The impact of reduced retention time is that, it will improve the efficiency of oil and water separation as shown in Figure 31 below.

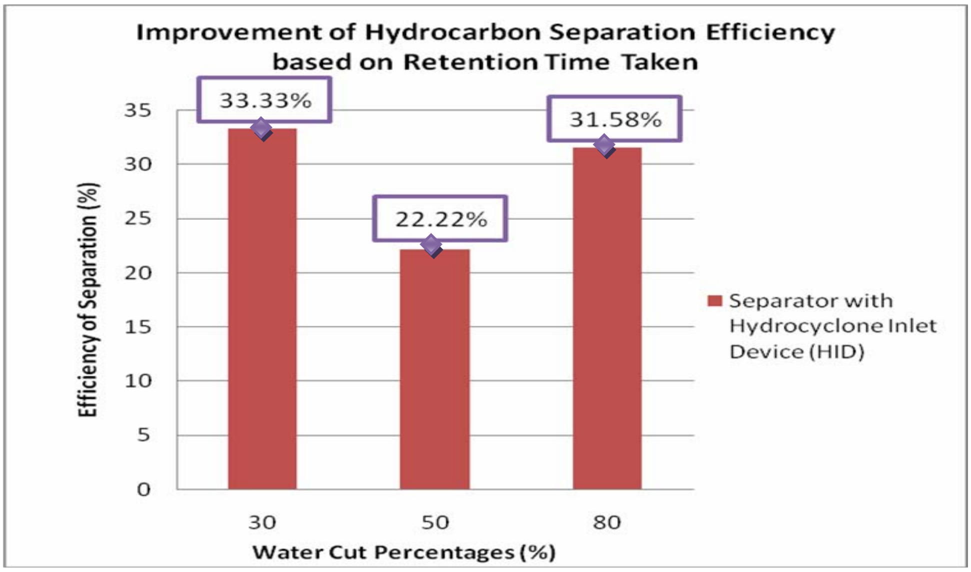


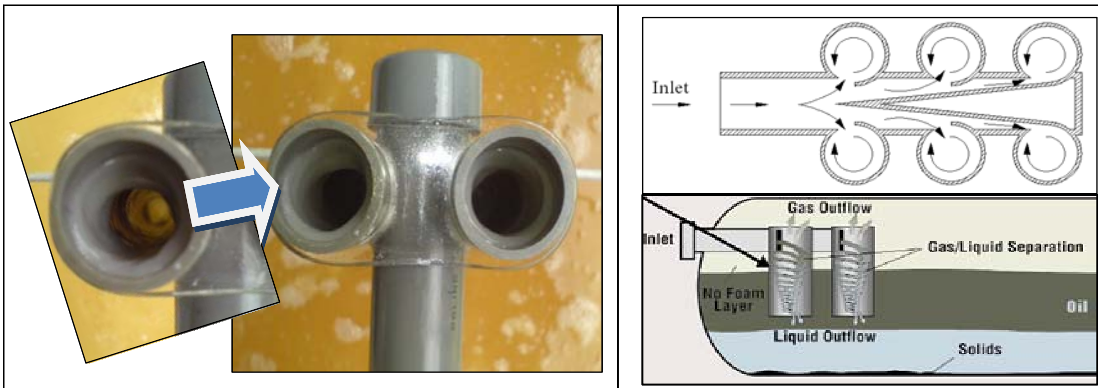
Figure 31: Improvement of Hydrocarbon Separation Efficiency

Figure 33 shows the improvement of oil and water separation efficiency, which is based on the retention time taken. From the graph, we can see that test 1 with 30% water cut shows the highest separation efficiency by 33%, followed by test 3 with 80% water cut, which is 32% and lastly goes to test 2 with 50% water cut, with the efficiency of 22%.

Overall, the results of the experiment show that the usage of HID in existing conventional separator was beneficial and had been proven with the experiments conducted. We can conclude that HID is compatible to all fields including field with high water cut production. As a summary, HID improve the oil recovery by 2-14% increment, emulsion can be reduced faster at first minute of separation by 35-50% reduction, reduced the oil and water retention time and thus increase the speed of separation and lastly, regardless of water cut percentage, HID will always improve the efficiency of separation by 20-35%.

4.2 EXPERIMENTAL OBSERVATION

Theoretically, the working principle of HID is that the inlet fluids will enter the tube tangentially with high velocity at the inlet manifold. It creates centrifugal force and drives the heavier fluids to spin outward. The rapidly spinning fluids create vortex within tube where phase separation occurs. It used centrifugal force to increased affective gravity force, so that the separation occurs more rapidly. It is observed that working principle of HID prototype is working according to the cyclonic effect theory as shown in the Figure 32 below.

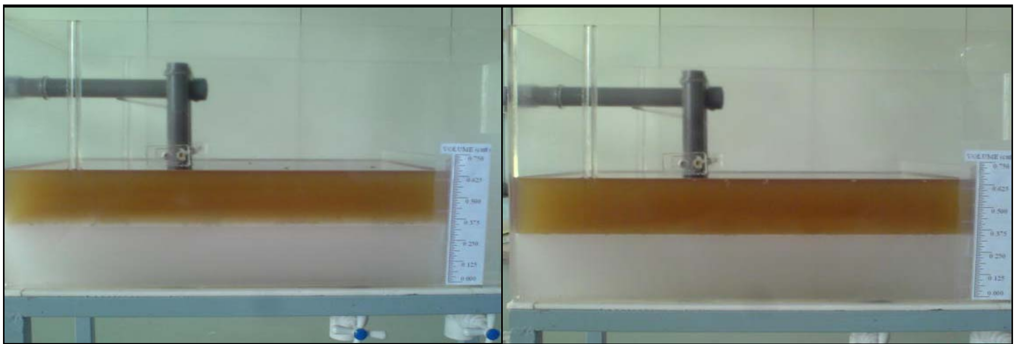


a) Cyclonic Effect in the Hydrocyclone Tube Observed during Experiment

b) Cyclonic Effect in Hydrocyclone Tube Theoretically

Figure 32: Comparison of HID Working Principle between Experimental and Theoretically

A picture of hydrocyclone test at 50% water cut has been taken as an example of how the experiment looks like just after the cyclonic separation take place and after it reached its retention time as shown in the Figure 33 below.



a) After 2 minutes run (At the early stage of separation)

b) After 7 minutes run (After it Reached its Retention Time)

Figure 33: Hydrocyclone Test at 50% Water Cut

4.3 EXPERIMENTAL LIMITATIONS

4.3.1 Type of Oil

The type of oil used throughout the experiment is Diesel Oil instead of Crude Oil. There are differences properties between those two types of oil such as its viscosity, density and composition. Diesel oil is the best alternative to replace the crude oil since the author could not get crude oil to conduct the experiments. Diesel oil is known to have properties closest to diesel oil.

4.3.2 Pressure Condition of Separator

The real production separator at the platform is using a pressurized vessel to separate the reservoir fluid. It is because at reservoir, the production fluid is in high temperature and pressure. In order to handle this fluid condition, certain separation module needs to have more than one production separator to reduce the fluid pressure in stages as shown in figure below.

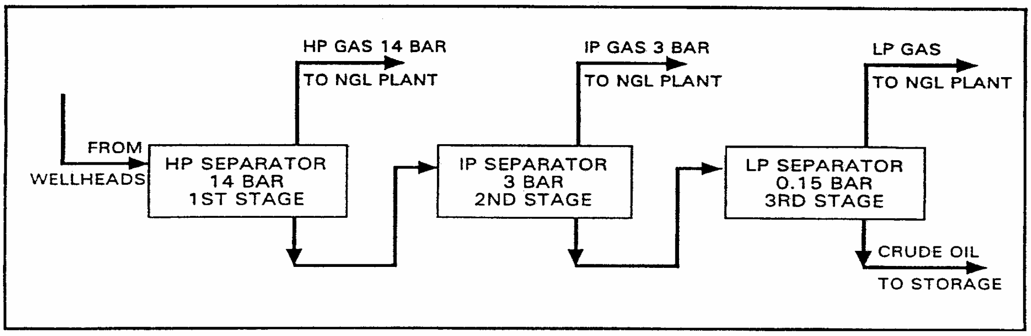


Figure 34: A Typical Configuration of Stage Separation Process

It is more efficient to separate the fluids in different stages. This ensures that the liquids are completely recovered. Stage separation is based on reducing the pressure of the liquid hydrocarbons in steps. This produces a more stable liquid. However, it is difficult to achieve the same fluid condition as the one in reservoir. Thus, the fluid condition used in the experiment is in ambient temperature and atmospheric pressure. Because of that reason, there is no requirement for stage separation and the author conducted the experiments in the atmospheric pressure vessel. Since the experiment conducted does not use the same fluid properties as the one in reservoir and does not use the pressurized vessel, the outcome results from the experiment may be differ.

4.3.3 Submersible Pump Limitation

In this experiment, the design capacity for the fluids mixture to be separated is 20 liters. However, during the operation only 18.5 liters of fluids mixture is been transferred from the fluids mixture container to the separator. This happened because the submersible pump inside the fluids mixture container is not able to pump up the fluids mixture below its suction head and leave about 1.5 liters of fluids inside the container. The outcome of this limitation may lead to the inaccuracy of parameters reading and thus affect the experimental results. This situation can be illustrated in figures below to get a clear view of what happened before and after test is conducted.

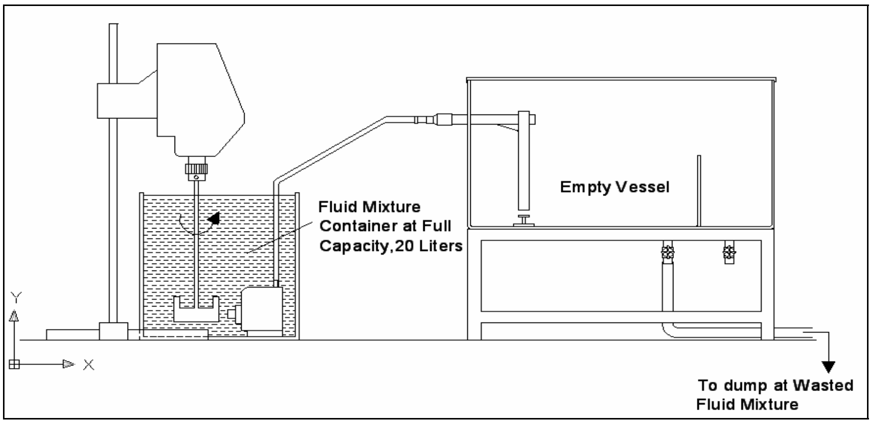


Figure 35: Experimental Layout before the Test is Conducted

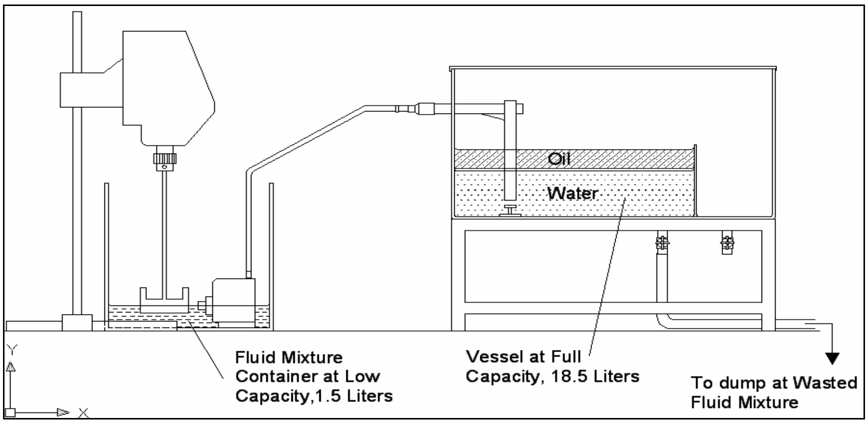


Figure 36: Experimental Layout after the Test is Conducted

It is recommended that future work on this experiment to use a centrifugal pump instead, which will be located outside the container. Another thing that needs to be taken into account is to make sure that the suction head of the pump is at the lowest level of the container so that it can transfer all the fluids mixture inside the container to the separator.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The project has been done in parallel with the objectives and time line established in the project. All the studies for applying the HID in conventional production separator for a processing offshore platform that were done are understood and successfully performed via the experimental conducted. This project is significant to the operatorship who manages the oil and gas at the offshore fields especially to mature oil fields with high water cut production. The results of this study can be used to suggest platform operator such as Petronas Carigali to consider installing hydrocyclone inlet device (HID) in its existing production separator.

The objective of Oil and Gas Company is to recover as much as the field can produce. The application of HID helps the operator by maximizing recovery of liquid hydrocarbon from fluid stream through improved and faster separation process. A prototype of HID and conventional separator had been constructed prior to perform the experiment. A total of six tests of experiments are conducted where three tests for each conventional separator and separator retrofitted with HID. These three tests are basically referred to the water-oil ratio percentages which are 30%, 50% and 80% which represent low, medium and high water cut in the production. The limitations of the prototype equipment have been discussed at length for future modification.

The main objective of this project is to investigate the effectiveness of HID in improving oil-water separation in high water-cut production. The level of effectiveness is measure in term of the improvement in oil recovery, the capability of emulsion reduction and oil and water retention time reduction in order to increase the speed of separation.

Based on the result of the experiments that had been conducted, it can be concluded that HID is compatible to be applied in the conventional production separator at oil fields no matter green or brown fields. The project has run successfully and the results outcome meets the main objective. Below are the key findings of this project:

1. Regardless of water cut percentages, HID can improve the efficiency of separation in term of oil retention time up to 35%.
2. HID helps to optimize the oil recovery up to 14% increment.
3. With HID, emulsion problem can be control since the emulsion thickness can be reduced faster than conventional separator at 1^{st} minute of separation by up to 50% reduction.
4. The cyclonic effect from the HID creates centrifugal forces which is thousand times greater than gravity force that helps to reduced oil and water retention time and thus increase the speed of separation up to 30%.

5.2 RECOMMENDATIONS FOR FUTURE WORK

For this Final Year Project, it is recommended to use crude oil instead diesel oil. It is because different type of oil will has different properties and composition. Crude oil is suggested in order to get better results since its properties is more similar to the reservoir fluid. The experiment for this project is suggested to conduct in a pressurized vessel prototype since the real production separator is a pressurized vessel type. The results from the experiment are suggested to be compared with the real data from the tested field. This is to make sure that the results gathered from the experiment are similar with the real data from the platform.

It is recommended that future work on this experiment uses a centrifugal pump instead of submersible pump, which will be located outside the fluid mixture container. It is because the submersible pump located inside the container is not able to deliver the fluid mixture below its suction head. The suction head of the pump should be oriented at the lowest level of the container so that it can deliver all the fluids mixture inside the container to the separator.

To enhance the separation process, it is suggested to perform some modification on the prototype such as adding oil and water level controllers with level float inside the vessel. This is to regulate the oil and water pad thickness in separator. As for hydrocyclone tube, the modification is suggested to see any changes in the result of separation performance. The example of modification to the hydrocyclone tube is by altering the cylindrical shape of the tube into a conical tube. Other than that, it suggested to put a free fall preventer inside the vortex tube in order to enhance the cyclonic effect. A free fall preventer is a device with 3 cutting edges looks like a small fan.

Besides that, the studies can also be done in an economical point of view by performing simple economic analysis. The analysis is based on the cost estimation of the installation of HID in the existing conventional separator. Besides, from this economic analysis, we are able to determine the required days to cover the total cost of the HID installation. This economic analysis is important to determine the feasibility of the installation not only according to the advantages and characteristic of the system, but economical prospects as well.

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APPENDICES

APPENDIX A: GANTT CHART

Attachment 1: Milestone for the First Semester of Final Year Project (Mechanical Engineering)

NO.	DETAIL / WEEK	1	2	3	4	5	6	7	MID SEM BREAK	8	9	10	11	12	13	14	SW	EW
1	**Selection of Project Topic**																	
	Preliminary Research Work																	
	- Introduction																	
	- Objective																	
2	- Literature Review																	
	** Problems in Separation Process*																	
	- Methodology																	
	- Preparation for Preliminary Report																	
	- Submission of Draft Preliminary Report				14/2													
3	**Submission of Preliminary Report**				15/2													
4	**Seminar 1**																	
	Project Work																	
5	- Data Gathering / Literature / Design Prototype																	
	- Preparation of Progress Report																	
	- Submission of Draft Progress Report																	
6	**Submission of Progress Report**									21/3								
7	**Seminar 2**																	
	Project Work Continue																	
8	- Preparation for Interim Report																	
	- Submission of Draft Interim Report																	
9	**Submission of Interim Report Final Draft**																	
10	**Oral Presentation**																	

Attachment 2: Milestone for the Second Semester of Final Year Project (Mechanical Engineering)

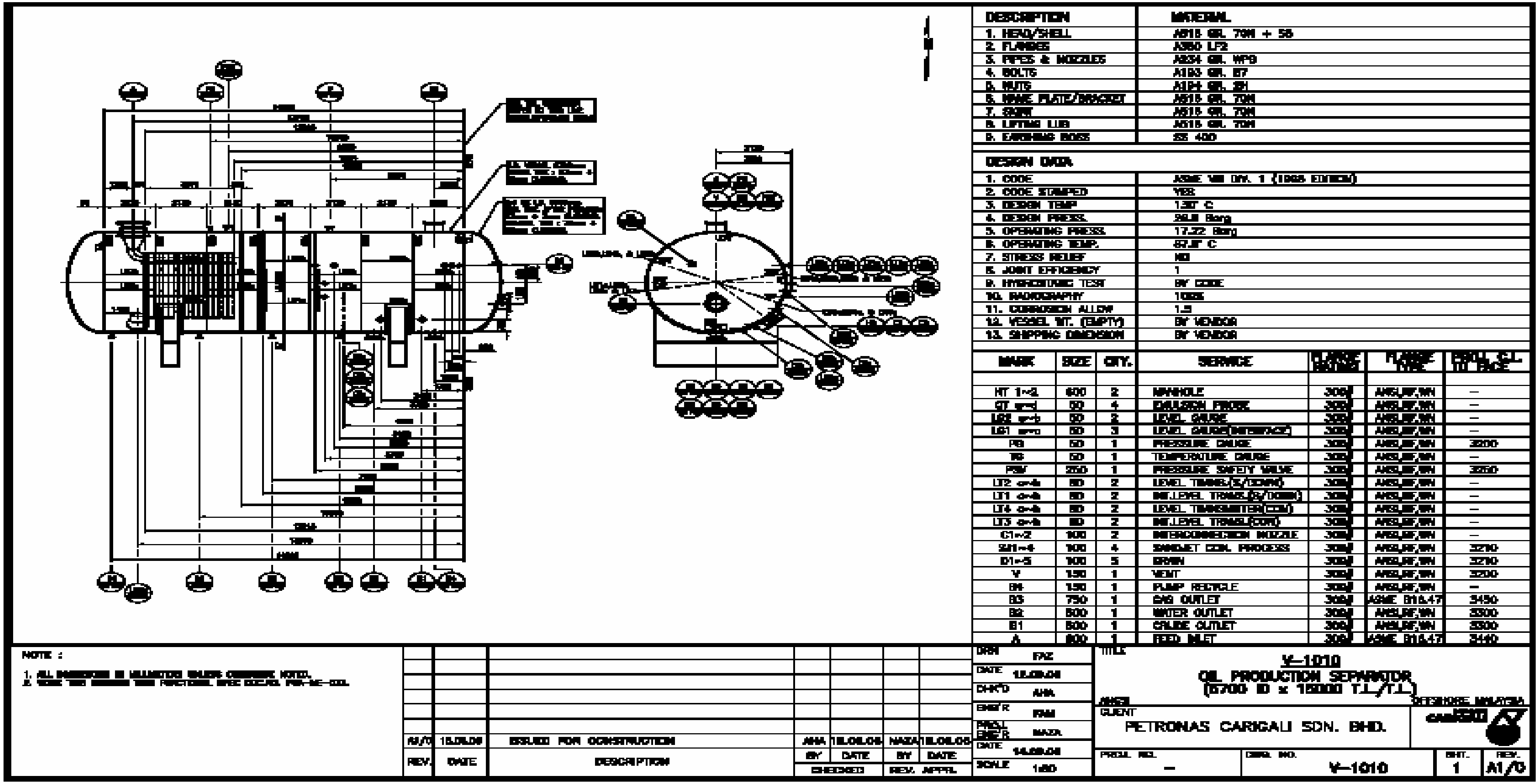
No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continue	■	■	■					Mid-Semester Break							
2	Submission of Progress Report 1				●											
3	Project Work Continue				■	■	■	■								
4	Submission of Progress Report 2									●						
5	Seminar (compulsory)										■	■	■			
5	Project work continue									■	■	■	■			
6	Poster Exhibition											●				
7	Submission of Dissertation (soft bound)													●		
8	Oral Presentation														●	
9	Submission of Project Dissertation (Hard Bound)															●

● Suggested milestone

■ Process

APPENDIX B:

P&ID OF ANGSI OIL PRODUCTION SEPARATOR, V-1010



APPENDIX C: EXPERIMENTAL

Attachment 1: Apparatus

- Measurement Beaker
- Mixer
- Wasted Fluids Mixture
- Connection Pipe
- Stopwatch
- A Container of Diesel Fluid
- Vessel
- Inlet Diverter
- Hydrocyclone Inlet Device
- Bottom Diverter Plate
- Submersible Pump
- Fluids Mixture Container

		
a)Vessel	b) Measurement beaker, Bucket, Inlet Diverter, Hydrocyclone Inlet Device, Connection Pipe, Bottom Diverter Plate, Submersible Pump	c) Fluid Mixture Container, Mixer, A Container of Diesel Fluid

Figure 1: Apparatus

Attachment 2: Experimental Layout

a) For Conventional Separator

Figure 2: Layout of the experimental setup for conventional separator

b) For Separator retrofitting with Hydrocyclone Inlet Device

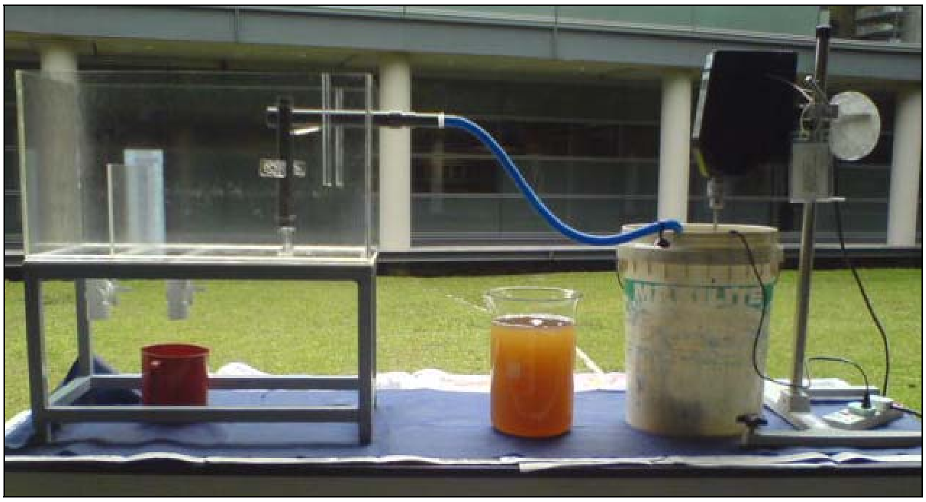


Figure 3: Layout of experimental setup for separator with hydrocyclone inlet device

Attachment 3: Experimental Procedures

a) <u>For Conventional Separator</u>

1. Prepare the apparatus according to the figure 2 shown.
2. Slot the inlet diverter into the vessel. (This is for the vessel to act as a conventional separator)
3. Arrange the apparatus according to the experiment layout as shown in figure 3.
4. Measure volume of water at 6 liters and volume of oil at 14 liters using the measurement beaker. This is for 30% water cut.
5. Combine both volume of water and oil into the fluid mixture container.
   (The total volume of the fluid mixture is 20 liters)
6. Switch on the mixer and set the motor speed at 80 rpm.
7. Wait for 3 minutes to make sure the oil and water are mix together, and then switch on the pump.
   (Now the mixture of oil and water will flow to the separator via pipeline)
8. Switch off the mixer and pump when the volume of the fluids mixture collected in the vessel is at 18.5 liters.
   (Measurement of the volume is taken from the mixtures thickness at 13.3cm; where at 1cm is equal to 1.394 liters)
9. Start the stopwatch just after the volume of fluids reached 18.5 liters and start take the reading of the parameters one minute after that.
10. Measure the water, emulsion and oil pad thicknesses every 2 minutes until the oil and water is settled to its phase respectively.
    (The fluid is consider as settled when the reading of measurement is constant for at least twice)
11. Record the retention time.
12. Dump the fluids mixture through the dump valve at the vessel outlet to the wasted mixture container.
13. Repeat step 3 to 11 for each different water cut. Detail as per below:

Test No.	Water Cut Percentage, (%)	Volume of Water, (ℓ)	Volume of Oil, (ℓ)
1	30	6	14
2	50	10	10
3	80	16	4

b) <u>For Separator Retrofitting with Hydrocyclone Inlet Device</u>

1. Prepare the apparatus according to the figure 2 shown.
2. Insert the hydrocyclone inlet device at the inlet vessel and install the bottom diverter plate at bottom of the vessel.
   (This is as to retrofit the existing conventional separator with hydrocyclone inlet device)
3. Arrange the apparatus according to the experiment layout as shown in figure 4.
4. Measure volume of water at 6 liters and volume of oil at 14 liters using the measurement beaker. This is for 30% water cut.
5. Combine both volume of water and oil into the fluid mixture container.
   (The total volume of the fluid mixture is 20 liters)
6. Switch on the mixer and set the motor speed at 80 rpm.
7. Wait for 3 minutes to make sure the oil and water are mix together, and then switch on the pump.
   (Now the mixture of oil and water will flow to the separator via pipeline)
8. Switch off the mixer and pump when the volume of the fluids mixture collected in the vessel is at 18.5 liters.
   (Measurement of the volume is taken from the mixtures thickness at 13.3cm; where at 1cm is equal to 1.394 liters)
9. Start the stopwatch just after the volume of fluids reached 18.5 liters and start take the reading of the parameters one minute after that.
10. Measure the water, emulsion and oil pad thicknesses every 2 minutes until the oil and water is settled to its phase respectively.
    (The fluid is consider as settled when the reading of measurement is constant for at least twice)
11. Record the retention time.
12. Dump the fluids mixture through the dump valve at the vessel outlet to the wasted mixture container.
13. Repeat step 3 to 11 for each different water cut. Detail as per below:

Test No.	Water Cut Percentage, (%)	Volume of Water, (ℓ)	Volume of Oil, (ℓ)
1	30	6	14
2	50	10	10
3	80	16	4

APPENDIX D: DIESEL OIL PROPERTIES

Properties	Guaranteed Level		Test Method
	Minimum	Maximum	
Colour (ASTM)	-	2.5	D 1500 / D 6045
Ash, mass %	-	0.01	D 482
Cetane Index	47	-	D 976 / D 4737
Total Sulphur, mass %	-	0.3	D 4294 / D 2622
Pour Point, ºC	-	15	D 97 / D 5950
Flash Point, ºC	60	-	D 93
Kinematic Viscosity @ 40ºC, cSt	1.6	5.8	D 445
Copper Corrosion (3h, @ 100ºC)	-	1	D 130
Water by Distillation, vol %	-	0.05	D 95
Sediment by Extraction, mass %	-	0.01	D 473
Conradson Carbon (10% residue, %(m/m) or Micro Carbon (10% residue), %(m/m)	-	0.1 0.1	D 189 D 4530
Distillation 90% Vol Recovery, ºC	-	370	D 86 / D 2887
Density @ 15ºC, kg/l	To be reported		D 1298 / D 4052
Electrical Conductivity , pSm	50	450	D 2624
Acid Number, mg KOH/g	-	0.25	D 974 / D 664

PRECAUTION

- May release Hydrogen Sulfide (H2S) gas which may be fatal if inhaled.
- Combustible Hydrogen Sulfide (H2S) gas may cause irritation to eyes.
- Prolonged or repeated skin contact may be harmful.
- If swallowed, DO NOT induces vomiting. May cause chemical pneumonitis.